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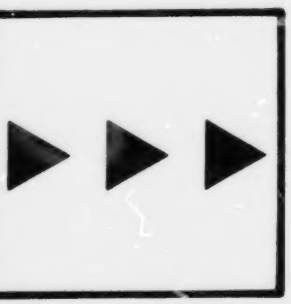
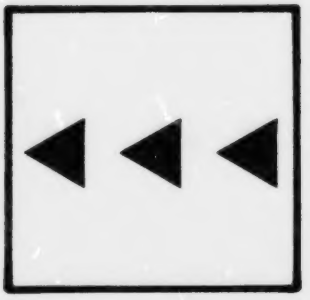


SURVEY OF THE STATUS OF REPAIR AND RECLAMATION TECHNOLOGY IN CANADA

Project RC99



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January 12, 1982

FINAL REPORT

by

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Welding Institute of Canada

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SURVEY OF THE STATUS OF REPAIR AND RECLAMATION TECHNOLOGY IN CANADA

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ABSTRACT

This report describes the results of a survey of weld repair and reclamation in Canada. A literature survey covered articles available for the period 1966 to 1981 dealing with weld repair and weld surfacing. Visits were also made to major companies involved with a range of technologies across Canada.

Consideration was given to identifying major types of components and materials which could justify the use of welding for repair and/or reclamation. A review of the welding processes and procedures describes several applications and examples for repair by welding.

This survey has shown that there are innumerable opportunities for the application of weld repair and reclamation of damaged components. Many of the examples documented were specific in nature, and their solutions would be of benefit to particular circumstances. In determining a program for the development of welding repair technology in Canada, which would be of benefit to the largest number of people, the survey points to the following recommendation:

A research program should be initiated to study the mechanical properties of weld repair procedures for steels used in thick sections, such as in pressure vessels. The use of post weld stress relief heat treatment, and its effects on the mechanical properties of the repaired structure should be incorporated in this program. Steel types A516, A533, and creep resistant steels of the Cr-Mo alloy group would cover the majority of installations of interest to Canadian Industry.

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SURVEY OF THE STATUS OF REPAIR AND RECLAMATION TECHNOLOGY IN CANADA

1. Introduction

The economic life of numerous engineering components is limited due to service failures or problems associated with excessive wear or corrosion. The annual costs directly related to maintaining the operation of plants and equipment are staggering. In 1977, the National Commission on Materials Policy in the United States estimated that wear costs in the nation amounted to $15 billion per year in materials alone (1). Gray also quotes that the yearly bill for corrosion repairs is even greater - $70 billion in 1975, according to figures released by the National Bureau of Standards (2).

Corrosion failures occur for a variety of reasons and are attributable to factors such as improper application, poor design and/or material selection, or misuse in service. The educating of engineers, technicians, and management in topics relating to corrosion processes could lead to considerable savings in both time and money.

As with corrosion, wear related problems are the result of several distinct phenomena. The significance of excessive wear is difficult to ascertain because it requires careful documentation in maintenance records; this is seldom done. Trends to higher production through extensive automation quite often require the use of capital intensive equipment. They are not

usually duplicated on a production line and they also have a long design life. Mechanical failures and breakdowns can be very expensive and in some instances can lead to plant shutdowns. The prediction of wear can be very beneficial since it would enable scheduled repairs to be done before failures occur.

Apart from general corrosion and wear, the effects of these phenomena are exacerbated where welding is involved and, in particular, in harsh environments. The results of a European survey on in-service damage to welds in the chemical engineering field for the period from 1975 to 1979 are shown in Figure 1. The majority of the damages were associated with corrosion processes, but the single most frequent failure was attributed to faults in production (22%). Fatigue failures (17%) and corrosion fatigue cracking (16%) combined with production faults account for 55% of the damage experienced in chemical plants. These three processes can be prevented by suitable design changes and control of production techniques, and would translate into considerable savings in capital and manpower.

Several options are available to remedy equipment failures. If repair is required on a piece of equipment which is crucial to plant operation, then repairs must be completed without undue delay, and optimum remedial techniques are not feasible. The other general category of repairs involves planned maintenance schedules to refurbish components which are known to deteriorate due to wear, abrasion, corrosion, etc. In the latter case, sufficient time is usually available to effect repairs and totally rebuild the defective areas.

Equipment is returned to operation by either replacing components which are responsible for the failure or by repairing the damage using one of numerous welding processes. In large operations, the inventory costs could be staggering and, therefore, weld related repairs are possibly less costly. The process used depends on the reason for the failure; the two general categories are known as build up and surfacing. The term build up involves repairing of cracks or adding material to surfaces which have been subjected to wear and/or corrosion. Surfacing repairs are usually thought of as hardfacing in which base materials are covered with a different alloy which can withstand service conditions better than the substrate.

The consumables used for build up are chosen with consideration given to the choice of welding process and accessibility and material properties required. All processes ranging from oxy-acetylene for small repairs to molten metal flood methods are available. The minimization of hydrogen through consumable selection and/or welding procedure is the prime consideration. The weld metal composition is specified to be compatible to the base material. The chemistries of welding products for build up are readily available and electrode selection does not pose any problems. The selection of consumables for hardfacing, however, is not an easy task. Many of the consumables are of a proprietary nature and their compositions are difficult to obtain. Each supplier has electrodes which they recommend for various applications, and it is extremely difficult for

the person involved to make the optimum choice. The alloys are designed to best combat one of the many types of wear which are caused by corrosion, abrasion, erosion, impact, or fatigue. A prerequisite for selecting a hardfacing product is a knowledge of the mechanism responsible for material degradation. This is oftentimes difficult and is frequently achieved through a trial and error basis.

A further requirement involved in the repair and reclamation procedure is the question of post-weld stress relief. This subject is addressed in the ASME Boiler and Pressure Vessel Code. The code requires stress relief after primary fabrication at temperatures in the neighbourhood of 625°C. This is accomplished by placing the vessel in a large furnace and allowing uniform temperature to be attained throughout the structure. When field repairs have been made by welding, a similar stress relief is frequently specified. However, attachments such as nozzles and piping restrict the use of general stress relief methods. Where accessibility is a problem, local heating is used to relieve welding stresses, but this can possibly increase localized stresses because of non-uniform temperature gradients. Various repair procedures such as the half-bead and temper bead techniques have been developed over the past couple of years to effect repairs without stress relief. These procedures have been used with success but they require considerable operator skill and a thorough understanding of the metallurgical changes caused to the baseplate. Sometimes repairs are required in radioactive environments or underwater, both of these examples are very difficult to stress relieve. In these instances the welds must remain as-welded.

The above discussion has pointed out some of the myriad of problems which must be addressed in the general field of repair and reclamation technology. The need for advances in education and applications is evident from the potential benefit to the industry in terms of reduced down-time, critical material shortages, and costs.

In response to a request from the Department of Supply and Services of the Federal Government of Canada, on behalf of CANMET, the Welding Institute of Canada has been asked to conduct a survey on the status of repair and reclamation technology in Canada. The objective of this report was to review the state-of-the-art and to define a program for the future development of weld repair technology. This was accomplished by a review of industrial requirements and a survey of available literature.

2. Information Collection

A list of reference articles was obtained using a computer search conducted by the Canada Institute for Scientific and Technical Information of the National Research Council, Canada. The key words used in the literature search were maintenance, repair, reclamation, and resurfacing. The following data bases were consulted:

Weldasearch	(1967 - 1981)
Metadex	(1966 - 1981)
Compendex	(1970 - 1981)

Selected articles were obtained from each listing to represent a wide range of examples of repaired or reclaimed components. Identification of major components and common repair techniques were tabulated to determine the frequency of the various reported examples. A bibliography of the articles was prepared using either the type of component or the particular class of consumable.

In order to obtain a broad picture of the significance and economic justification for weld repair in Canada, major industries were identified and contacts were made with representative companies, if practical. The key segments of industry were grouped in the following major headings:

I Steelmaking (Stelco)

II Transportation

III Mining, oil sands (Syncrude)

IV Electrical utilities (Ontario Hydro)

V Pulp and Paper (Abitibi-Price)

The companies listed in parentheses were contacted and interviews were conducted to establish the following information:

(a) typical components needing repair;

(b) figures indicating the economic justification;

(c) special environments, difficulty of access, limitations due to size;

(d) present methods and procedures; and

(e) any difficulties encountered and directions for improvements.

Major consumable suppliers were also contacted to determine the types of products available and the recommended repair procedures.

3. Survey Results

The information collected in this survey covered a wide range of materials and applications. The information was categorized into general headings in order to highlight the salient features. Where possible, examples of major components which had been either repaired or reclaimed were documented.

3.1 Literature Survey

The computer searches generated approximately 350 titles relating to maintenance and repair welding; but some duplication was encountered amongst the three data bases, thus reducing the number of different articles. Some of the references were found in many different journals and conference proceedings which were not readily available. Only the literature which was at the disposal of the Welding Institute of Canada was included.

The major headings chosen to classify the articles can be broadly identified as either relating to particular processes or providing a specific example, and they are as follows:

(a) stresses, stress relief

(b) processes and consumables

(c) steelworks, rolls

(d) pipelines, drilling rigs

(e) castings

(f) pressure vessels

(g) turbines

(h) properties

(i) mine and mill equipment

(j) rail

The classification of the 214 articles reviewed by the author into the 10 headings listed above resulted in the diagram shown in Figure 2. The heading entitled processes and consumables (23%) included the greatest number of articles. The next most numerous category was castings (17%), followed by pipelines (mainly offshore) and drilling rigs (16%), steelworks repairs (11%), and pressure vessel (9%). The other headings were related more to specific examples and discussed the procedures involved in the weld repair. Articles describing requirements for stress relief (2%) and properties of the repaired parts (3%) received the least attention.

The literature search demonstrated that weld related repairs could be successfully employed to restore a range of articles from castings to high technology turbine components, and also that repairs were applicable to all types of industries.

The articles which were considered to be the most significant are listed in the bibliography. The headings are not quite the same as the ten categories in Figure 2. It was rationalized that the articles dealt with

either repair processes and consumables or specific repair examples. The processes and consumables articles referenced include detailed procedures for alloy selection for hardfacing (4,5,6) or for weld repair of cracks (7,8), or describe the techniques (9). Specific examples, of weld surfacing and weld repair will be referred to as necessary in the text.

3.2 Industrial Survey

The technology associated with weld repair has been available for a number of years, but, as is often the case, the transfer of knowledge to the industrial sector is not rapid. The economic justification for weld repair and/or reclamation is clearly evident from the literature, however, its use is not widespread. In order to ascertain the importance of weld repairs in Canada, interviews were conducted with representative companies from diverse fields across Canada.

A detailed account of the industrial visits is included in Appendix A. The reports give relevant examples of the types of problems encountered in industry and the methods used to remedy them. Repairs generally fall into one of two categories; those associated with the repair of cracks, and those used to build up surfaces which have worn excessively. Cracks were encountered throughout a wide range of components and many solutions followed the same procedures for repair. On the other hand, wear related problems of specific alloys were isolated to special circumstances. The major examples of equipment repairs determined in the interviews will be discussed in the next section. Whenever available, current costs and pertinent articles from the literature will be referenced.

3.2.1 Hardfacing in the Mining Industry

Mining operations involve handling and processing of large tonnages of ore daily. The impact and abrasive nature of the ore movement causes extensive wear of the handling and process equipment. The extraction of oil sands in Northern Alberta by mammoth draglines and bucketwheels is a good example. Selective hardfacing of teeth and the bucket sides has resulted in improved operating life. Spare bucket teeth can be quickly replaced without losing production time, i.e. during machine maintenance, the sharp teeth reduce both power consumption and time.

Hardfaced materials are used extensively for crushing ore before it is sent to the mill for metal extraction. Two types of commonly used crushers are shown in Figures 3 and 4. The rotor type impactor is shown to be extensively surfaced with wear resistant material on all parts. The hammers in the hammer mills (Figure 4) are subject to abrasion primarily on the leading face. The rebuilding of hammers at Falconbridge Nickel Mines was extensively studied in order to find the best repair method and choice of consumables (11). Laboratory and field tests were conducted and their investigation proved to be very beneficial. The results of the experiments allowed build up material, hardfacing material, and deposition costs to be reduced from $95,000 to $48,000 in the first year of operation, while the life of the hammers was increased from 2 days to an average of 6 days before rebuilding was required.

Overall, worn manganese steels are routinely built up and hardsurfaced in the mining industry. Other typical examples include repair of mantels and bowls from cone crushers and rebuilding of rail car wheels and grinding rolls.

3.2.2 Coatings for Fossil Energy Conversion

The world-wide situation where petroleum resources have become very costly has increased the use of coal in power stations and industrial boilers. It is expected that by 1990, the world trade in coal will more than double to more than 400 million tons a year. This surge in world coal demand should triple Canada's coal exports in the eighties (12). The exports would include both the so-called steam or thermal coal and the more expensive metallurgical, or coking coal. It is anticipated that by 1990, Canada's coal exports would be in the order of 59 million tons, 25.7 million tons would be thermal coal, and the remainder, 33.2 million tons would be coking coal.

Material deterioration problems are encountered in both coal conversion and coal utilisation systems. Coal conversion uses direct combustion for producing steam for turbines to generate electricity. In ref. (13) it was stated that steam temperatures are limited to 550°C, primarily because of fireside corrosive attack from ash deposits, which become particularly severe between 600°C and 700°C. Alkalies and sulphur are the principal sources of the problem, which is expected to become more severe as utility firms switch to low-grade coals having higher ash contents. Also,

increased thermal efficiency and the possible use of more exotic cycles require higher working fluid and heat exchanger tube tempratures. This combination of lower grade coals and higher required operating temperatures in the future clearly previews the need for more resistant materials at reaction surfaces. Corrosion and erosion problems are anticipated to be more severe with processes used to convert the coal to gaseous fuel, particularly with internal components in the gasifiers. In some instances, "gas velocities up to 30 m per second and temperatures to 1650°C may be reached with pressure up to 10.5 MPa, though not all simultaneously."(13).

At the present time, aluminide coatings are being used for corrosion resistance which is not provided by the boiler material. Although the coating is low cost, it can cover complex geometries, and exhibits good surface adhesion, it has some disadvantages related to field repair and welding; field repair is not feasible, and welding must be performed prior to coating.

The utilisation of surface coatings is of particular interest to Ontario Hydro and, more generally, the Canadian Electrical Association, for applications in coal-fired generating stations. This is reflected by the fact that the CEA has a current study underway to determine the applications for hardfacing in the coal-handling industry.

3.2.3 Erosion Protection of Slurry Pipelines

Metal erosion of pipelines transporting a slurry of sand and water is often encountered. Typical slurries are the tailings from a metal extraction operation or the silt recovered from dredging of rivers and lakes. The frequency of required repairs is affected by the nature and velocity of the material flowing in the pipe. Hardfacing the inside of the pipe with a material known to possess good resistance to abrasion can lead to substantial increases in the life. The cost saving using an iron-chrome-carbon overlay versus a carbon steel pipe has been reported as shown in the table below (14). Test results have shown that on straight pipe, an extended life of 30:1 is possible with a life span of 18:1 on elbow bends.

OPS-T200X Dredge Pipe Opposed to Carbon Steel Pipe

Cost versus Maintenance Time Saved for One Year Period

	OPS-T200X Pipe	Carbon Steel Pipe
Initial Cost	$ 80,769	$ 34,919
Maintenance for Pipe Replacement*	--	$ 36,000
New Pipe Cost Every Three Months	--	$139,676
Lost Production Cost (Unknown)	--	--
Approx. Total Cost	$ 80,769	$210,595
Approx. Savings with Triten Pipe	$129,826	

* Shutdown of three days minimum to replace pipe at $3,000/day every three months.

3.2.4 Reconditioning of Steel Mill Rolls

The technology and equipment necessary to rebuild or resurface steel rolls has been available since at least the 1960's and there have been various processes patented. An European survey published in 1970 (15) indicates the types of rolls that can be repaired and the range of compositions.

Reconditioning of rolls can be done by partial rebuilding of worn grooves or by complete rebuilding to original dimensions of a roll used to the minimum useful diameter which is known as scrap size. This is done by using high rates of deposition processes, usually submerged arc or bulkweld processes.

A large roll weighing 40 tons used until scrap size and then completely rebuilt with six tons of metal can take two weeks or longer to finish the welding and machining. The price of rebuilding the roll is 5% to 10% less than the price of a new roll. In terms of output, rebuilding a roll once can result in a 50% cost reduction per ton of rolled product. On the average, rolls rebuilt with suitable materials outlast the original carbon steel rolls by 1.3 to 2 times. On the other hand, the life of rebuilt rolls is only 0.6 to 0.8 times the service life of hypereutectoid alloyed steel or iron, these rolls generally have higher wear resistance.

Apart from the economics of rebuilding in which a cost comparison includes:

(a) the cost of new rolls;

(b) the cost of rebuilt rolls; and

(c) the service life of both parts,

in plant facilities for welding and machining are required. This type of capital expenditure and daily costs are not justified unless there is a sufficient volume of repairs. SARCLAD (submerged arc cladding) was developed in a joint program between British Steel Corporation and ESAB in the early 1970's (16). The revenue requirement for the development work was met mostly by the sale of rolls within British Steel Corporation. The equipment was built in one of the shops of BSC's River Don Works, Sheffield. The development of the method has proven successful, and the technology is marketed worldwide.

In Canada, the visit to Stelco revealed that they are not interested in roll repair but their neighbour, DOFASCO, does have an ongoing roll maintenance program. Information on which either decision was based was not available.

Apart from the large rolling mills, conveyor rollers used in continuous casting mills, such as at LASCO in Whitby, are resurfaced as required. The hot steel shapes cause rapid abrasion of the surface material. Hard wear-resistant alloys which do not require impact resistance are being evaluated to obtain the most cost effective solution.

A number of articles indicated that blast furnace bells and hoppers could have their service life extended by hardfacing (10,17). The coating properties in this case should be able to withstand mechanical abrasion and erosion by hot gases. In the example given (17), the service life has been extended from 3 to 5 years to 8 to 9 years with hardfacing.

3.2.5 Underwater Repair Welding

An area of potential development with the current offshore discovery of oil and gas in Canada is the construction and repair of the facilities necessary to collect and transport the resources; this includes pipelines, platforms, well heads, and ships. A survey conducted by the Welding Institute of Canada (18) confirmed the interest of Esso, Panarctic, and Dome in the field of underwater repair welding. The most frequent repair methods involve hyperbaric welding (19), with the technology having been developed for European applications in the North Sea.

A recent article (20) outlines Dome Petroleum Ltd's decision to build a $350 million East Coast shipyard on McNab's Island in Halifax Harbour. Although "it would be cheaper and easier to get the ships - which include 25 200,000 ton icebreaker tankers at a cost of $330 million each - from Japan or South Korea, Dome is prepared to put national considerations first both in buying and in manning the ships in Canada" (20). Apart from the $75 million a year in direct salaries, the Canadian shipyard

steel consumption is expected to rise from 80,000 tons to more than 250,000 tons a year when the Dome yard is in production (20). This announcement gives direct proof of their policy to develop offshore repair technology in Canada since offshore structures will require maintenance welding at some point.

3.2.6 Repair of Cracks

The most frequent application for repair welding was to repair cracks. The examples given in Appendix A cover a wide range of materials from mild steel to HK-40 (0.4%C, 25%Cr, 20%Ni), and also all types of castings. Failure of a component could result from a mechanical overload with the fracture initiation point located at a notch or stress concentration. Fracture initiation is also quite frequently found to be associated with regions of local accelerated corrosion or wear. Some of the more unusual repair situations are discussed below.

3.2.6.1 Reformer Tube Repair

Steam reformer furnaces are used for many different applications in the oil refinery and petrochemical industries. The high operating temperatures and harsh environments manifest themselves in creep and corrosion related problems. Recent examination of reformer tubes at Syncrude revealed cracks in several tube assemblies, and a decision was required as to whether the tubes should be replaced, or whether they could be repair welded. Approximate costs for retubing were $8,000,000 compared to an estimated $1,000,000 for weld repair.

At typical service temperatures, secondary carbide formation in HK-40 appreciably lowers the ductility of the material and destroys its weldability; both can be restored by a high temperature solution annealing heat treatment after welding. A system developed by the Esso Research and Engineering Company is capable of utilising portable equipment for solution annealing in the field (21). The article describes the procedure and temperatures used for successful repairs; the mechanical and metallurgical properties of the repaired sections were comparable to those before welding.

3.2.6.2 Pressure Vessel Repair

Periodic inspection is done on pressure vessels, whether they are in nuclear or non-nuclear installations. Defects caused by service conditions, or those missed in the initial inspection, which are reported as a result of routine inspection, are undesirable. In the past, defects of any kind were not allowed and had to be repaired. Advances in fracture mechanics, however, have been the basis for reanalysis of a repair or no-repair decision; defects below a critical size will not lead to brittle failure.

Limited inspection time restricts the routine examination to critical locations, such as those associated with attachment welds, nozzle corners, and support corners. Internal attachment welds in stainless clad vessels are also very prone to hydrogen embrittlement and subsequent cracking.

As with the reformer tubes, service exposure can lead to temper embrittlement which reduces both the fracture toughness and the weldability. It will take many years to collect this data (22) and compile it in a useful form. Temperature embrittlement through service exposure has only recently been identified as a potential problem and thus the link between operating parameters and embrittlement is not available.

Once a decision has been made to repair a defect, the welding procedures must be specified. A half-bead welding technique is allowable for field repair (23), and a temper bead technique (24) has also been used (25). The relative merits of each procedure are discussed in the article by Lawson and Mills (25). Either repair method precludes the use of a stress-relief treatment following repair welding, thus not adding unacceptable creep deformation due to heat treatment.

An investigation (26) into the mechanical properties of weld repairs in castings has shown that the weld metal, and not the HAZ, has the poorest toughness. A stress relief treatment was specified to improve the fracture toughness of the weld metal for its intended service. This may apply also to the temper bead and half-bead repair techniques, specifically, should the allowable defect size be evaluated for the weld metal of the repair or the heat-affected zone? This is not answerable at the present time.

3.3 Survey Summary

The examples given in the preceding section only touched on some of the various types of components or structures which have been repaired or reclaimed by welding processes. They were intended only to highlight some of the major repairs and point out means of problem solution and potential benefits.

A list of the major articles in the field of repair and reclamation technology is contained in the bibliography under appropriate headings. As previously noted, most articles and literature available from the various suppliers describe the numerous processes and consumables and their applications. They should be referenced to provide greater detail than can be presented here.

4. Repair and Surfacing

The area of repair and reclamation by welding generally involves surfacing of a base metal to either build up worn sections to their original dimensions or to provide specific properties to withstand corrosion and/or wear. Repair of cracks is accomplished by removing sufficient base metal to ensure that the crack is no longer present, and allowing for access to conduct a repair procedure, then the component is built up to its original dimensions. The choice of a suitable repair procedure is dependent on the availability of consumables, whether the

component can be welded in situ or has to be removed, and also whether qualified personnel and suitable equipment are accessible. The most commonly used processes and their benefits are described below, and examples of typical applications are discussed.

4.1 Repair of Cracks

A common maintenance problem involves the repair of cracks which have been noticed because of a failure or through routine inspection using non-destructive methods. Structural members and process equipment are fabricated from low or intermediate carbon steels, and data is readily available concerning repairs of these steels.

The most widely used process for the repair of cracks is the shielded metal arc process. There are several good reasons for the popularity of the use of stick electrodes, such as the following:

(1) low equipment cost and maintenance;

(2) can be used for on-site maintenance and repair;

(3) welding can be conducted in areas remote from the power source by using welding cables of suitable length;

(4) can be used in all positions;

(5) can be used where access is limited;

(6) a wide range of alloy compositions are available; and

(7) most repairs do not require specialized welder training.

The only possible limitation of the process is the relatively low deposition rate compared to semi-automatic welding processes.

In a repair situation, there is the distinct possibility of hydrogen cracking due to welding. In order to avoid it, adequate preheat and low hydrogen consumables are required. The preheat is specified to prevent excessive hardening in the heat-affected zone of the repair weld, and it also allows the hydrogen to diffuse away from the weld area, thus reducing the risk of cracking. Low hydrogen electrodes (in the baked condition) are the only consumables specified for repair of pressure components using the half-bead or temper bead methods specified in ASME Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components" (23).

The wide range of compositions available with stick electrodes makes it very easy to obtain electrodes which match the baseplate; matching properties does not necessarily mean that the compositions are identical. A slightly undermatched electrode is used so that the weld deposit has more ductility than the base material and thus reduces the risk of cracking.

A summary of the repair techniques involved in crack repair will be described in section 5.

4.2 Build up and Surfacing

Surface coatings for build up, or repair of wear or corrosion damage, can be applied using arc welding or flame-spraying techniques. The main interest in this survey, apart from repair by welding, is repair methods using arc welding processes. Therefore, the subsequent discussions will not include flame-spraying, even though it is being used in industry.

Welding processes suitable for surfacing range from oxy-acetylene welding, to manual and semi-automatic processes, to fully automatic submerged arc and bulkweld processes; the corresponding deposition rate ranges from 0.5 kg/hr to 45 kg/hr. The selection of a process depends on the complexity of the part to be welded and the extent of the area to be repaired. For some alloys, the consumables are only produced for a limited number of processes, and this can dictate the method used for surfacing. The classification of surfacing consumables and the processes available for depositing the coatings are listed in Table 1 (6).

The composition of the consumables, and the resulting chemical composition of the weld deposit, gives the surface its wear and/or corrosion resistance. The amount of dilution from the baseplate changes the chemical composition of the coating. Dilution greatly reduces the wear resistance of the surface by producing changes in the microstructure. The wear resistance results from the mixture of hard particles (carbides) in a tough matrix; chemical dilution degrades this resistance by changing the microstructure and mechanical properties of the matrix.

The least dilution occurs in oxy-acetylene welding (5%), increases with manual metal arc welding (10-30%), and is greatest for submerged arc welding (10-40%). The dilution is directly related to the energy involved in the surfacing process, and the welding technique. Subsequent weld layers will experience less dilution and approach the chemical composition of the consumables (9).

Taking into account both repair welding and arc welding to produce coated surfaces, it appears that manual metal arc welding (SMA) is the most prevalent process used. The other most frequent welding processes used are submerged arc welding (SAW) and gas shielded metal arc welding (GMAW). The relative percentages of uses and applications are difficult to determine because suppliers do not release that type of information. However, a review of papers in various publications and manufacturers' literature indicates that SMA, SAW, and GMAW are the most widely used methods for repair and surfacing.

5. Weld Repair Procedures

In the preceding section, reference was made to the repair of cracks; and it was noted that the repair procedure depended on whether the repair was to be made on a structural part or to a pressure containing structure.

5.1 Repair Without Stress-Relief

When repairs are to be made to pressure retaining components in the nuclear industry, the repair procedures are specified in the ASME Boiler and Pressure Vessel Code, Section XI (23). This particular section describes the removal of the defect, the handling of consumables, the required welding procedures, and the qualification of the welding procedure. The repair procedure uses a half-bead welding technique which does not require a post-weld heat treatment.

The half-bead technique involves grinding half of the first weld bead before subsequent welds are deposited. This tempers the first weld pass and thus reduces the risk of cracking. However, if grinding is excessive, there is the possibility that the second weld will penetrate to such a depth that its HAZ will not be tempered, and the purpose of the method will have been lost. A refinement of this repair method is the temper bead technique which utilizes a sequence of weld passes such that the weld sequence alone can temper the welds without grinding. The location of weld repairs can make it difficult to gain access with grinders for removing the initial pass in the half-bead technique; also, grinding greatly increases the repair time. In order to avoid these two problems the temper bead method is preferred for weld repairs of components which are not stress relieved.

In both the half-bead and temper bead repair procedures, the weld bead size and the weld location must be carefully controlled by the welder; this requires careful supervision and documentation and an operator who has sufficient knowledge to understand the metallurgical changes involved in the repair. The consequences of welding procedures on several different materials must also be taken into account. For example, creep-resisting steels can experience reheat cracking due to the weld thermal cycles alone. Control of the bead size and heat input through the use of electrodes of the proper size and welding technique can prevent reheat cracking. As a repair procedure for most industrial applications, the half-bead and temper bead welding methods are not suitable. The technological input and the components which would be repaired in this manner are commonly found in high technology areas such as electrical generation facilities and oil sands reclamation. These operations have the expertise and need for the specialized repairs involving the techniques mentioned above, but on the whole, industry is mainly concerned with the repair of structural components, and these are discussed next.

5.2 General Repair Technique

The repair of cracks in low, or intermediate carbon steel structures or equipment is a common maintenance problem. The procedures to be followed in a repair situation are straightforward. A general procedure for the repair of cracks and a list of precautions that will minimize distortion are outlined in an article by Paolini (8), and are given below:

(a) Locate and identify all cracks.

(b) Remove cracked material by grinding and/or arc-air gouging, keeping excavations to a minimum.

(c) Re-weld the excavations, if necessary; keeping distortion to a minimum.

(d) Dress all repairs; blend the welds carefully into the main material; leave smooth radii; avoid stress raisers such as notches, or sharp changes in cross section.

(e) Carefully check all repairs with magnetic particle, dye penetrant or close visual inspection.

In order to specify a suitable repair procedure, the chemical composition of the damaged material must be determined. This can be done at several commercial laboratories if time permits, or can be obtained from equipment literature. Once the material is identified, the consumables, and the use of preheat and postheat, and possibly stress relief, can be specified.

There is always the possibility of delayed or hydrogen cracking after weld repairs due to a combination of high stresses and a large mass of material which would produce hard brittle microstructures in the weld heat-affected zone. The crack susceptibility increases with hydrogen content and thus the repair procedures (preheat, postheat) are designed to minimize the hydrogen in the weld area. The preheat and interpass temperatures vary according to the material being repaired. The temperatures for construction grade steels are listed in Table 5.4 of CSA

Standard W59-1977, "Welded Steel Construction", which is given as Table 2. Temperatures for other metals and alloys not covered in this standard are given in Table 3.

Apart from using elevated temperature treatments, peening has often been used to reduce distortion and residual stresses. However, because of the uncertainties with regards to the effects of peening, variation in peening practices amongst welders, and the lack of a peening procedure, its use is often discouraged on low and intermediate carbon steel weldments. Experience has supported the usefulness of peening on higher alloy and tool steels, but there is still debate on aspects such as hot or cold peening.

5.3 General Techniques for Minimizing Distortion

Paolini also outlines general methods which could be used to minimize distortion for both production and repair welding, and these are as given here:

(1) Distribute and balance the shrinkage forces by special welding techniques and sequences such as:

   (a) Welding on the second side of the joint before completing the first side, or welding alternate layers on both sides of the joint;

   (b) Welding on both sides of a joint simultaneously;

   (c) Using a back-step sequence, wandering sequence, or cascade sequence;

(d) Presetting the joint to compensate for the distortion resulting from weld shrinkage.

(2) Restrain the parts in jigs or fixtures, or use temporary strong backs or holding lugs.

(3) Select a joint with the least practical amount of weld metal. Double vee or double U groove joints have less weld metal than single sides.

(4) Select a welding process that will use as few passes as possible and a low heat input. Fast welding speeds at high amperage result in less distortion than slow welding speeds. For example, submerged arc automatic welding will distort only about 75% as much as manual welding with the same amount of weld metal.

(5) Proper peening of a weld can reduce distortion by about 20%. Because of the possibility of harming the weld deposits and notch toughness, peening should only be used after careful consideration by the designer or welding engineer.

5.4 Weld Surfacing

Arc weld surfaces are specified to either rebuild worn components or are an integral part of the originally designed component. Before worn parts can be reclaimed, it is necessary to remove the damaged materials and ensure that all existing cracks are removed before welding. A thorough cleaning and degreasing of the part will prevent unknown contaminants from entering the weld area.

The size and configuration of a component, as well as the availability of a consumable of suitable composition, determines whether surfacing will be done using stick electrodes, gas shielded metal arc processes, or submerged arc welding. Special applications of materials for corrosion and wear can also be deposited with other welding methods.

The wide range of surfacing materials available, and the numerous procedures used to deposit the coatings, makes it virtually impossible to outline general procedures for surfacing. The only useful suggestion would be thorough crack removal and cleaning as mentioned above.

There are many companies who specialize in manufacturing and marketing consumables to be used for hardfacing. The compositions of their proprietory electrodes are difficult to obtain, and an additional complicating factor is that there are no standards pertaining to these electrodes and wires. The consumer is, therefore, quite often led to believe that a particular company has the solution to all of his/her welding problems; this is possibly true in some cases. In order to come to a logical and cost effective repair procedure, there are a number of alternatives which should be considered before selecting a supplier and his products. The factors that will affect the (a) choice of process and (b) choice of consumables have been collected in two Tables (4 and 5) which were discussed in a seminar at the Welding Institute entitled "Surface Coatings for Savings in Engineering" (5).

The experience of service personnel in the maintenance repair business can be used to the customers' advantage after they have become familiar with the various alternatives. Numerous articles and manufacturers' examples can be obtained for references of surface repair procedures. The articles are extremely valuable and modifications are easily made when circumstances are not identical. A number of case histories described in section 3 showed the justification of repair by surfacing.

The pattern of a hardfacing deposit can significantly increase its effectiveness; some of the most common types are shown in Figure 5. The rationale behind these techniques are explained in an article by Shewchuk et al (11). Deposits laid perpendicular to the flow of fine ores allow the ore to pack between them, and the ore then runs against itself, and not the base metal. Large rocks tend to chip off perpendicular beads, but hardfacing deposits parallel to the flow of ore can serve as rails and provide a flow path for the rocks. The advantages of both techniques are applied when ore of mixed sizes is being handled by laying a diamond or herringbone pattern. A dot pattern can be used in the case of high cost hardfacing alloys which have a tendency to spall off in rugged applications, or can be used to minimize local overheating and distortion of hard to weld base metals.

usions and Recommendations

e exists the possibility of potential savings in materials and labour ughout Canada by utilising welding processes for repair and lamation. This is evident from the numerous examples given in the t. An exact figure is unobtainable because most industries do not equately document their repair procedures.

estoration of a damaged component to its original application can be done y either repairing cracks or by resurfacing. The cost effectiveness of a particular solution could justify the repair procedure, but there is no guarantee that it is the optimum solution. It is not possible to allocate sufficient manpower and resources to formulate the best possible solution in each case, and quite often the necessary information is unavailable.

Following discussions with people throughout Canada involved with plant maintenance, and consumable suppliers, and after an extensive review of the literature, the author has developed several opinions, some of which are:

(1) Incidents of weld related repairs are not reported in sufficient detail to be of assistance when the problem recurs.

(2) The repair of cracks is still believed to be akin to magic. It is an art that has been developed over the years by welding personnel, and they tend to keep their experience shrouded in mystery.

(3) Technological advances in the development of consumables for surfacing have not been transferred to the user. Ignorance on the part of supervisors and maintenance personnel is unavoidable.

(4) Repairs are often conducted haphazardly without sufficient consideration to the circumstances and environments responsible for the repair. The condition of the components before and after weld repair is not well understood.

In the course of this project, it has become clearly evident that there is a definite need for the development of welding repair technology in Canada. Benefits can be manifested in short term as well as long term results. Some recommendations for study to derive immediate benefits are listed below:

(1) Information relating to degradation of materials in severe environments is needed to enable a fracture mechanics approach to be used to decide whether or not repair of a defect revealed by inspection is required.

(2) The toughness of a material is known to be affected by weld repairs with, or without, stress relief. In some cases, the weld metal toughness is the dominating factor. The variation of mechanical properties occurring with different repair procedures would be invaluable information. This type of information could be collected for a wide range of the most common alloys.

Other projects identified during the survey are specific in nature and the benefits would be limited to particular industries. Examples of projects which could be undertaken were mentioned during the industrial visits and are included in Appendix A. Studies on surface reclamation processes and consumables would benefit mining companies and dredging operations where slurries are transported in pipelines. The agricultural industry, mining, and earth moving operations would realize direct usefulness from studies on the abrasion resistance of surface coatings. These two examples are evidently only two of the many programs suitable for repair or reclamation mentioned in this survey. In all instances, a collaborative effort between the technical research facility and the industrial application would have to be established. The proven examples are necessary to convince people of the economic benefits possible in repair welding.

A proposal to study material properties following repair welding is included as Appendix B. The proposal outlines an experimental program which would be of particular use to Canadian interests.

Long term development of repair technology can be accomplished through introduction of maintenance and repair welding courses in the training of welders, engineers, and managers. Educating these people in the benefits of repair welding and the numerous techniques available seems to be the best method for developing the technology which is already

available. The system necessary for education and specialized seminar topics is already established at the Welding Institute of Canada. Recent examples of well-received meetings were the "International Seminar on Submerged-arc Welding" and the "Hi-Tech Applications in Welding Processes". The programs for these two seminars are included in Appendix C. The speakers, many of whom came from abroad, are world leaders in their respective fields and contributed to the overall success of the seminars. It is envisioned that similar special sessions on repair welding could also be arranged. The topics could range from common sense techniques for crack repair in carbon steels to subjects such as microstructural aspects of wear surfaces for abrasion resistance. People involved in repair and/or reclamation on a daily basis would be approached to present a talk in their specialized areas. Topics such as the factors affecting the choice of process (Table 4) and the choice of consumables (Table 5) could also provide the basis for related repair technology seminars. The topics presented in a series of seminars could then be collected at a later date and compiled into a handbook format. This would be the most expedient and worthwhile approach to collect a compendium of repair technology.

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TABLE 1 (from Ref. 6)

Classification and Typical Compositions of Consumables for Weld Deposited Surfaces for Wear Protection

Table 1 Classification and typical compositions of consumables for weld deposited surfaces for wear protection

Classification			Typical composition % (● indicates possible presence)													Deposited hardness	Deposition method*					
Group	Type		Fe	C	Cr	Mn	Mo	V	W	Co	Ni	B	Nb	Cu		HV	OA	MMA	MIG	FCAW	TIG	SA
1 Steels	1	Carbon steels	Balance	0·35												up to 250	●	●			●	
	2	Low alloy steels	Balance	0·1–0·5	●	●	●	●	●		●	●				250–650		●	●	●	●	●
	3	Martensitic Cr steels	Balance	0·1–1·7	10–15	●	●	●	●		●					350–650		●	●	●		●
	4	High speed steels	Balance	0·3–1·5	10 max	5	10	3	20	12						600–700		●	●			●
	5	Austenitic stainless steels	Balance	0·07–0·2	17–32	●	●				7–22					(1) 200 (2) 600						
	6	Austenitic Mn steels	Balance	0·5–1·0	●	11–18	●	●			●					(1) 200 (2) 600		●				
	7	Austenitic Cr Mn steels	Balance	0·3–0·5	12–15	12–15	●	●			●					(1) 200 (2) 600		●		●		●
2 Irons	1	Austenitic irons	Balance	4	12–20	●	●				●					300–600		●		●		
	2	Martensitic irons	Balance	1–4	1–10	●	●	●	●		●	●				600–750		●		●		
	3	High Cr austenitic irons	Balance	3–6	20–40	●	●				●					600–750	●	●	●	●		●
	4	High Cr martensitic irons	Balance	2–3	20–30	2 max										600–750	●	●	●	●		●
	5	High Cr complex irons	Balance	2–5	20–40	●	●	●	●	●	●	●				600–800		●	●	●		●
3 Nickel alloys	1	Nickel	8	2		1					85 min					180		●				
	2	Nickel copper	3–6	0·35–0·85		2·5					60–70			25–30		130		●				
	3	Nickel iron	Balance	2		1					45–60					200		●		●		
	4	Ni Mo Cr W	5	2·5	30 max		17		15	12	Balance		7			250–500	●	●	●		●	
	5	Ni Cr B	●	●	5–25		●	●			Balance	1–5				200–750	●	●			●	
	6	Ni Mo Fe	5–20				20–30				Balance					200–300		●				
4 Cobalt alloys	1	Co Cr W low alloy		0·7–1·4	25–32				3–6	Balance						350–600	●	●	●		●	●
	2	Co Cr W medium alloy		1·0–1·7	25–32				7–10	Balance						400–500	●	●	●		●	●
	3	Co Cr W high alloy		1·7–3·0	25–35				11–20	Balance						500–650	●	●	●		●	●
	4	Co Cr W Ni alloys		1·2–2·0	20–25				10–15	Balance	20–25					350–650	●	●	●		●	
5 Copper alloys	1	Bronzes		up to 40%Zn balance Cu												130			●		●	
	2	Silicon bronzes		up to 4%Si balance Cu												80–100			●		●	
	3	Aluminium bronzes		8–15%Al balance Cu												130–139		●	●		●	
	4	Tin bronzes		4–12%Sn balance Cu												40–110		●	●		●	
6 Tungsten carbide	Maximum 60% tungsten carbide granules in an iron base matrix or can be in a copper, cobalt or stainless steel matrix															1800 (granules)	●	●		●	●	
7 Chromium boride paste	1				80–85								15–20			750–1100						

(1) As deposited (2) Work hardened *OA Oxy-acetylene MMA Manual metal arc MIG Metal inert gas FCAW Flux cored arc TIG Tungsten inert gas SA Submerged arc

TABLE 2 (from ref. 8) Minimum Preheat and Interpass Temperatures

Thickness of Thickest Part at Point of Welding (Inches)	Welding Process									
	Shielded Metal-Arc — SMAW With Other than Basic Electrodes		SMAW with Basic Electrodes		GMAW (Gas Metal-Arc Welding)		FCAW "CH" Designations			
	FCAW	With Other than "CH" Designated Classifications	SAW				SAW			
							Carbon or Alloy Steel Electrodes (Neutral Flux)		Carbon Steel Electrodes (Alloy Flux)	
1	2		3		4		5		6	
	G40.21	ASTM	G40.21	ASTM	G40.21	ASTM	G40.21	ASTM	G40.21	ASTM
	42W 44T 44W	A36 A53 Gr. B A500 Gr. B A501 A516 Gr. 55, 60 A529 A570, Gr. D, E	38T 38W 42W 44T 44W 50T 50W 50A 55T 55W 60A	A36 A53 Gr. B A441 A500 Gr. A, B A501 A516 Gr. 55,60,65,70 A529 A570 Gr. D, E A572 Gr. 45,50,55 A588 A606 A607 Gr. 45,50,55 A618 A633 Gr. A, B, C, D	60T 60W 70T 70W	A572 Gr. 60,65,70	100Q	A514 A517	100Q	A514
Up to ¾ incl.		none*		none*		50°F		50°F		50°F
Over ¾ to 1½		150°F		50°F		150°F		125°F		200°F
Over 1½ to 2½		225°F		150°F		225°F		175°F		300°F
Over 2½		300°F		225°F		300°F		225°F		400°F

*When the base metal temperature is below 32°F, preheat the base metal to at least 50°F, and maintain this temperature during welding.

Notes:

(1) Welding shall not be done when the ambient temperature is lower than 0°F, except with the express consent of the Engineer.

(2) When the base metal is below the temperature listed for the welding process being used and for the thickness of the material being welded, it shall be preheated (except as otherwise provided) in such manner that the surfaces of the parts on which weld metal is being deposited, are at or above the specified minimum temperature for a distance equal to the thickness of the part being welded—but not less than 3 inches—both laterally, and in advance of the welding.

Preheat and interpass temperatures must be sufficient to prevent crack formation. For Q and T steel, the maximum preheat and interpass temperature shall not exceed 400°F for thickness up to 1½ inches inclusive, and 450°F for greater thicknesses. Heat input, when welding Q and T steel, shall not exceed the steel producer's recommendations.

(3) Preheat and interpass temperature may be reduced when approved by the Engineer and/or the Bureau for techniques established by the Contractor which will guarantee satisfactory properties for the joint in its full length.

TABLE 3 (from ref. 8) Preheat Temperatures for Metals and Alloys

METAL GROUP	METAL DESIGNATION	APPROXIMATE COMPOSITION – PERCENT								METAL DESIGNATION	RECOMMENDED PREHEAT
		C.	Mn.	Si.	Cr.	Ni.	Mo.	Cu.			
PLAIN CARBON STEELS	PLAIN CARBON STEEL	BELOW .20								PLAIN CARBON STEEL	UP TO 300°F
	PLAIN CARBON STEEL	.20-.30								PLAIN CARBON STEEL	300°F-350°F
	PLAIN CARBON STEEL	.30-.40								PLAIN CARBON STEEL	350°F-500°F
	PLAIN CARBON STEEL	.40-.50								PLAIN CARBON STEEL	500°F-600°F
CARBON MOLY STEELS	CARBON MOLY STEEL	.15-.30					.50			CARBON MOLY STEEL	300°F-500°F
	CARBON MOLY STEEL	.30-.30					.50			CARBON MOLY STEEL	400°F-600°F
	CARBON MOLY STEEL	.30-.35					.50			CARBON MOLY STEEL	500°F-600°F
MANGANESE STEELS	SILICON STRUCTURAL STEEL	.35	.50	.50						SILICON STRUCTURAL STEEL	300°F-600°F
	MEDIUM MANGANESE STEEL	.30-.35	1.0-1.75							MEDIUM MANGANESE STEEL	300°F-600°F
	SAE T 1330 STEEL	.30	1.75							SAE T 1330 STEEL	400°F-600°F
	SAE T 1340 STEEL	.40	1.75							SAE T 1340 STEEL	500°F-600°F
	SAE T 1350 STEEL	.50	1.75							SAE T 1350 STEEL	600°F-700°F
	12% MANGANESE STEEL	1.25	12.0							12% MANGANESE STEEL	USUALLY NOT REQUIRED
HIGH TENSILE STEELS (SEE ALSO STEELS BELOW)	MANGANESE MOLY STEEL	.30	1.60	.30			.25			MANGANESE MOLY STEEL	300°F-600°F
	JALTEN STEEL	.20 MAX.	1.20	.30				.40		JALTEN STEEL	400°F-600°F
	MANTEN STEEL	.20 MAX.	1.25	.30				.20		MANTEN STEEL	400°F-600°F
	ARMCO HIGH TENSILE STEEL	.12 MAX				.50 MIN.	.05 MIN.	.25 MIN.		ARMCO HIGH TENSILE STEEL	UP TO 300°F
	DOUBLE STRENGTH @ 1 STEEL	.12 MAX.	.75			.50-1.25	.10 MIN.	.50-1.00		DOUBLE STRENGTH @ 1 STEEL	300°F-600°F
	DOUBLE STRENGTH @ 1A STEEL	.20 MAX.	.75			.50-1.25	.10 MIN.	.50-1.00		DOUBLE STRENGTH @ 1A STEEL	400°F-700°F
	MAYARI R STEEL	.12 MAX.	.75	.35	.5-1.0	.25-.75		.40		MAYARI R STEEL	UP TO 300°F
	OTISCOLOY STEEL	.12 MAX.	1.25	.10 MAX.	.10 MAX.			.50 MAX.		OTISCOLOY STEEL	300°F-600°F
	MAX HIGH TENSILE STEEL	.10-.20		.75	.60	.17	.10 MAX.	.35 MAX.	Zr. .12	MAX HIGH TENSILE STEEL	UP TO 300°F
	CROMANSIL STEEL	.14 MAX.	1.25	.75	.30					CROMANSIL STEEL	300°F-600°F
	A. W. DYN-EL STEEL	.11-.14						.40		A. W. DYN-EL STEEL	UP TO 300°F
	CORTEN STEEL	.12 MAX.		.25-1.0	.5-1.5	.55 MAX.		.40		CORTEN STEEL	300°F-600°F
	CHROME COPPER NICKEL STEEL	.12 MAX.	.75		.75	.75		.35		CHROME COPPER NICKEL STEEL	300°F-600°F
	CHROME MANGANESE STEEL	.40	.90		.40					CHROME MANGANESE STEEL	400°F-600°F
	YOLOY STEEL	.05-.20	.5-1.0			1.75		1.0		YOLOY STEEL	300°F-600°F
	HI-STEEL	.12 MAX.	.6	.3 MAX.		.55		.5-1.25		HI-STEEL	300°F-500°F
NICKEL STEELS	SAE 2015 STEEL	.10-.20				.50				SAE 2015 STEEL	UP TO 300°F
	SAE 2115 STEEL	.10-.20				1.50				SAE 2115 STEEL	300°F-350°F
	3½% NICKEL STEEL	.10-.20				3.50				3½% NICKEL STEEL	300°F-600°F
	SAE 2315 STEEL	.15				3.50				SAE 2315 STEEL	300°F-500°F
	SAE 2330 STEEL	.30				3.50				SAE 2330 STEEL	300°F-500°F
	SAE 2330 STEEL	.30				3.50				SAE 2330 STEEL	300°F-600°F
	SAE 2340 STEEL	.40				3.50				SAE 2340 STEEL	400°F-700°F
MEDIUM NICKEL CHROMIUM STEELS	SAE 3115 STEEL	.15			.60	1.25				SAE 3115 STEEL	300°F-600°F
	SAE 3125 STEEL	.25			.60	1.25				SAE 3125 STEEL	300°F-500°F
	SAE 3130 STEEL	.30			.60	1.25				SAE 3130 STEEL	400°F-700°F
	SAE 3140 STEEL	.40			.60	1.25				SAE 3140 STEEL	500°F-600°F
	SAE 3150 STEEL	.50			.60	1.25				SAE 3150 STEEL	600°F-700°F
	SAE 3215 STEEL	.15			1.00	1.75				SAE 3215 STEEL	300°F-500°F
	SAE 3230 STEEL	.30			1.00	1.75				SAE 3230 STEEL	500°F-700°F
	SAE 3240 STEEL	.40			1.00	1.75				SAE 3240 STEEL	700°F-1000°F
	SAE 3250 STEEL	.50			1.00	1.75				SAE 3250 STEEL	900°F-1100°F
	SAE 3315 STEEL	.15			1.50	3.50				SAE 3315 STEEL	500°F-700°F
	SAE 3325 STEEL	.25			1.50	3.50				SAE 3325 STEEL	700°F-1100°F
	SAE 3435 STEEL	.35			.75	3.00				SAE 3435 STEEL	900°F-1100°F
	SAE 3450 STEEL	.50			.75	3.00				SAE 3450 STEEL	900°F-1100°F
MOLY BEARING CHROMIUM AND CHROMIUM NICKEL STEELS	SAE 4140 STEEL	.40			.95		.20			SAE 4140 STEEL	600°F-800°F
	SAE 4340 STEEL	.40			.85	1.75	.25			SAE 4340 STEEL	700°F-900°F
	SAE 4615 STEEL	.15				1.80	.25			SAE 4615 STEEL	400°F-600°F
	SAE 4630 STEEL	.30				1.80	.25			SAE 4630 STEEL	500°F-700°F
	SAE 4640 STEEL	.40				1.80	.25			SAE 4640 STEEL	600°F-800°F
	SAE 4820 STEEL	.20				3.50	.25			SAE 4820 STEEL	600°F-800°F
LOW CHROME MOLY STEELS	½% Cr-½% Mo. STEEL	UP TO .15			.50		.25			½% Cr-½% Mo. STEEL	400°F-600°F
	½% Cr-½% Mo. STEEL	.15-.25			.50		.25			½% Cr-½% Mo. STEEL	500°F-600°F
	1¼% Cr-½% Mo. STEEL	UP TO .15			1.00		.50			1¼% Cr. ½% Mo. STEEL	500°F-700°F
	1¼% Cr-½% Mo. STEEL	.15-.25			1.00		.50			1¼% Cr. ½% Mo. STEEL	600°F-800°F
MEDIUM CHROME MOLY STEELS	5% Cr-½% Mo. STEEL	UP TO .15			5.00		.50			5% Cr-½% Mo. STEEL	500°F-600°F
	5% Cr-½% Mo. STEEL	.15-.25			5.00		.50			5% Cr-½% Mo. STEEL	600°F-700°F
	5% Cr-1% Mo. STEEL	.15 MAX.			5.00		1.00			5% Cr-1% Mo. STEEL	600°F-800°F
PLAIN HIGH CHROMIUM STEELS	12-14% Cr. TYPE 410	.10			13.00					12-14% Cr. TYPE 410	300°F-500°F
	16-18% Cr. TYPE 430	.10			17.00					16-18% Cr. TYPE 430	300°F-500°F
	25-30% Cr. TYPE 446	.10			26.00					25-30% Cr. TYPE 446	300°F-600°F
HIGH CHROME NICKEL STAINLESS STEELS	18% Cr. 8% Ni. TYPE 304	.07			18.00	8.00				18% Cr. 8% Ni. TYPE 304	
	25-12 TYPE 309	.07			25.00	12.00				25-12 TYPE 309	
	25-20 TYPE 310	.10			25.00	20.00				25-20 TYPE 310	
	18-8 Cb. TYPE 347	.07			18.00	8.00			Cb. 10X C	18-8 Cb. TYPE 347	
	18-8 Mo. TYPE 316	.07			18.00	8.00	2.50			18-8 Mo. TYPE 316	
	18-8 Mo. TYPE 317	.07			18.00	8.00	3.50			18-8 Mo. TYPE 317	

TABLE 4 (from ref. 5)
Factors Affecting Choice of Surfacing Process

Difficulties can be experienced in choosing between surfacing processes and, quite often, several alternatives could be used effectively. This check list includes many of the considerations desirable in determining the final choice; factors of importance will vary between applications so only a selection from the list will be of significance in any particular case.

An orderly, by no means mandatory, progression has been attempted and emphasis is again placed on the possibilities offered by changing the base metal composition when a coated component is substituted for one made out of the solid.

A. GENERAL FACTORS	COMMENTS
1. Where is the work to be done: in-house or subcontracted?	Policy decision
2. Surfacing processes available	What processes are available in the works?
3. Available forms of particular surfacing alloys	Some alloys available for only one or two processes
4. Labour available	What expertise exists in relation to various methods?
5. Weight of coating to be applied	Not submerged-arc for an ounce nor gas welding for a ton
6. Surface area to be protected	Wide and thin needs different treatment from narrow and deep
7. Numbers to be surfaced	Can items be grouped; do they lend themselves to mechanisation?
8. Desirability of mechanising	What are the economics? What are the problems with possible processes?
9. Capital expenditure	How much; can it be justified; is it available?
10. Design of assembly	Can this give application difficulties?
11. Design changes possible	Would these overcome anticipated problems?
12 Method of joining component to other parts of product	Previously welded, brazed, soldered shank fit, bolted, etc.

TABLE 4 (continued)
Factors Affecting Choice of Surfacing Process

B	SERVICE AND AIDS AVAILABLE	COMMENTS
1.	Compressed air	Essential to some processes and methods of surface preparation
2.	Gases	Town's gas, oxygen, acetylene, propane required by some processes
3.	Electricity	AC and/or DC: what voltage and current maxima?
4.	Lifting equipment	Take process to job or job to process?
5.	Grit blasting	Essential to some methods; beware contamination of other work
6.	Positioning equipment	Can welding position be selected?
7.	Turning fixtures	Speeds, feeds, location
8.	Heat treatment facilities	May affect location of work; could determine process selected.
9.	Straightening equipment	Need for holding tolerances could determine process
10.	Fume extraction and dust collection	What can be tolerated from the surfacing process?
11.	Personnel protection	Could lack of facilities limit process choice?

C	THE JOB-ITS SIZE AND CONDITION OF BASE METAL	COMMENTS
1.	Size of job	How do different surfacing methods measure up to job?
2.	Weight of job	For certain processes, is there a problem in achieving bonding temperature?
3.	Location	What problems arise in moving process to work, or vice versa?
4.	Shape	Can it be rough machined or grit blasted?

TABLE 4 (continued)
Factors Affecting Choice of Surfacing Process

SIZE AND CONDITION	COMMENTS
...TAL	
...y of surface	Can the process be applied to the surfaces to be coated?
...a of surface	Different processes have different minimum requirements
...e imposed by adjacent	Will change in thermal mass prove difficult; are there heat sensitive parts nearby?
...f base metal	If unacceptable can process heat input be kept low enough?
...e of base metal	Affects preparation possibilities and choice of surfacing methods
...bility	Can determine choice of build-up process
...surface treatments remaining	May limit application of surfacing techniques
...e of component at high ...ture	May need precautions to limit general temperature rise.
...CE PREPARATION NEEDS	COMMENTS
...ent available	Flame spraying cannot be used if wire brushing only is available
...feasible for job	Even with grit blasting available it might be impossible to reach surface to be coated
...e required in other areas	Process choice might assist; could be necessary to build up other areas as well to achieve balance
...ting required	Could be combined with surface preparation
...achine registers	If accurate machining is involved, precise positioning is essential
...maintain machining datum	The process chosen would neither obliterate nor distort
...possible	Could be more useful to some processes than other

TABLE 4 (continued)

E	PROPERTIES REQUIRED IN COATING	COMMENTS
1.	Thickness of deposit	Spraying could be ideal for 0.020 in.; no real choice for 1.00 in.
2.	Porosity in coating	If required, a fusion process is to be avoided
3.	Adhesion to substrate	If a high bond strength is needed, a sprayed deposit is not ideal
4.	Is cracking in the coating permissible?	Can widen scope in choice of process as well as of alloy
5.	Are interactions with base metal deleterious?	If so process must minimise heat input to base
6.	Structure required in surfacing alloy	Electrode, rods and powders vary greatly in macrostructure of deposit
7.	Melting point of deposit	If required to be high, self-fluxing alloys are not suitable
8.	Machinability of coating	Deposit roughness is an important factor; heating and cooling rates can affect hardness of coating
9.	Is degradation of surface coating a problem?	Process time/temperature can modify coating
10.	Need deposit metallurgy be controlled?	Process temperature can alter composition/structure significantly
F	FINISHING NEEDED ON DEPOSIT	COMMENTS
1.	What surface finish is necessary?	Can the part be used 'as deposited'; need it be polished?
2.	What dimensional accuracy is required?	Surface uniformity and heat input regulation varies with processing
3.	What is the function of the surface?	What is required from the coating and the method of putting it on?
4.	How much distortion is permissible?	Must heating be uniform; must it be minimal
5.	What machines are available for finishing?	e.g. spark machining could obviate need for precise contour control
6.	What assembly undertaken after surfacing?	Will oxidation or overspray interfere with subsequent manufacture?

TABLE 5 (from ref. 5)
Factors Affecting Choice of Consumables for Surfacing

For any job, several surfacing alloys may often be selected to meet the conditions of the job: some may perform better than others, they may vary in price, different application processes may be required, and so on. Below are listed, without specific order, many of the considerations which will assist selection and the answers may help coating experts in giving advice about choice of coating material.

One factor which is frequently overlooked in original manufacture is the desirability of changing the base metal to facilitate surfacing and, maybe, reduce costs. In the case of repairs, at times it is appropriate to make a new component in a simple, readily available material, and to build on to this a coating having the required properties.

A GENERAL FACTORS	COMMENTS
1. Is it an original job?	Look for possible snags
2. Are similar applications known?	If so, guidance may be available
3. Need test pieces be processed?	Important if snags and difficulties are anticipated
4. What is the service temperature?	Look for required properties in the surfacing alloys
5. What is the working environment?	Corrosive, oxidising, abrasive, etc?
6. What surfacing processes are available?	What does the company possess? What can be used by subcontractors?
7. What surface preparation methods are available?	Again, either in the company or available to the company
8. What surface preparation methods are feasible?	Plant available may be too small; the design may prevent use
9. Will future repairs be needed?	Some materials can be built up again, others need removal before salvage
10. Are base metal changes possible?	Often enables the choice to be extended and better alloys selected
11. Are design changes possible?	Can affect choice of process and, in turn, choice of alloys

TABLE 5 (continued)

A GENERAL FACTORS		COMMENTS
12. What is the nature of adjacent or rubbing materials?		Consider properties of surfacing alloys, electrochemical corrosion, etc.
13. How much cost will the work bear?		Surprisingly, often overlooked until much time has been spent on evaluating the job
B PROPERTIES REQUIRED OF APPLIED SURFACE		**COMMENTS**
1. What is the overall function of the surface?		Wear is a complicated problem and the particular environment must be critically assessed
2. What degree of adhesion to substrate is necessary?		A rock crusher is stressed differently from a metallised window frame
3. What compressive stresses are to be imposed?		A drilling bit differs from a zinc sprayed bridge member
4. What porosity is desired or undesirable?		Desirable for paint adherence, and lubrication, taboo in corrosive chemical plant
5. What is nature of the mating surface?		Can set up a corrosive emf, abrade, etc.
6. Is lubrication available or required?		Could widen choice. Might make porosity desirable
7. Microhardness needed in deposit		Often specified but may not accurately determine wear resistance
8. Microhardness structure desired in constituents		Resistance to a heavy metal load needs a different structure from, say, high stress abrastion
9. Resistance to:	abrasion	High stress, low stress, rubbing or impact
	corrosion	Often affected by minor alloying constituents; consider service stresses in relation to stress corrosion
	oxidation	Wet, or dry, static, or dynamic
	erosion	Can be solid, liquid, or gaseous
	seizure	Mating surfaces and conditions are important

TABLE 5 (continued)

B	PROPERTIES REQUIRED OF APPLIED SURFACE	COMMENTS
10.	Is coefficient of friction important?	Can be very low with many surfacing alloys
11.	What impact forces encountered in use?	Has toughness to compromise hardness; is subsurface toughness an advantage?
12.	Is thermal conductivity important?	At times, yes; at times a thermal barrier may be engineered
13.	Is electrical conductivity important?	Bond properties, conductivity of applied metal, tendancy to oxidise in service

C	METALLURGICAL AND CHEMICAL PROPERTIES OF BASE METAL	COMMENTS
1.	What is composition of the sub-strate?	Possibly the most important question if heating is involved in surfacing
2.	Have dissimilar metals been used in manufacture?	Can be calamitous; can provide unexpected problems
3.	Has surfacing been carried out previously?	Can it be rebuilt or must the coating be removed?
4.	What previous surface treatment given?	Many possibilities, see Table 3
5.	How much cold work is locked up in the part?	Will it distort on heating; need it be stress relieved and straightened?
6.	Is the metallurgical condition important?	Need specific metallurgical structures preserved or developed?
7.	What is the surface hardness?	Can it be prepared by grit blasting or machining
8.	Are there any weld heat-affected zones?	Can radically affect hardenability
9.	Has brazing been used in assembly?	Could the assembly come apart at the surfacing temperature?

TABLE 5 (continued)

D	PHYSICAL CONSIDERATIONS RELATING TO THE BASE METAL	COMMENTS
1.	Coefficient of thermal expansion	Can one match it with the applied alloy?
2.	Location of work	Application problems will influence choice of process
3.	Thickness of build-up needed	A different alloy would be selected for a surface coating 1.000 in. thick compared with 0.010 in. thick
4.	Size of job	A needle valve seat differs from a railway track
5.	Shape of part	An extrusion screw presents a different problem from a digger tooth
6.	Thermal mass	The thickness of substrate and severe cross-sectional changes are significant factors
7.	Area to be surfaced	A 0.25 in. square may suffice for one job but several square yards may need protection on another
8.	Condition of surface	Rust, dirt, oil impregnated iron and other conditions may be found
9.	Proximity of temperature-sensitive areas	Could be electrical motor insulation or a soldered joint
10.	Have interference fits been used?	Heating could disrupt these fits

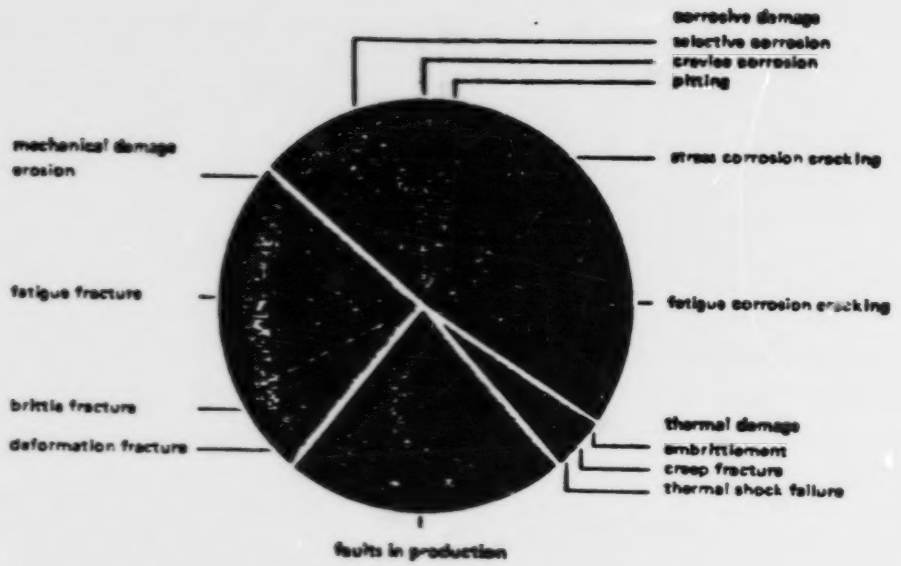

Figure 1: In-service damage to welds broken down by type (period covered 1975 to 1979)

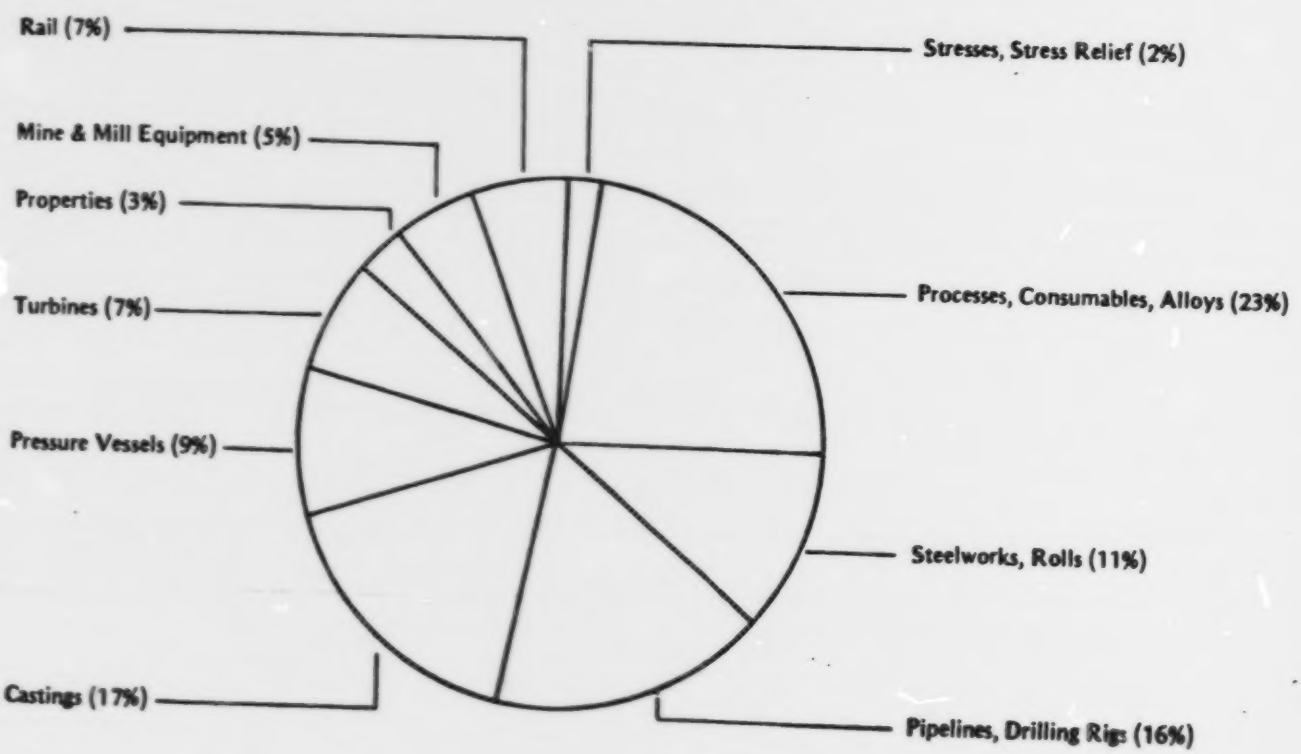

Figure 2: Results of literature survey on weld repair and reclamation.

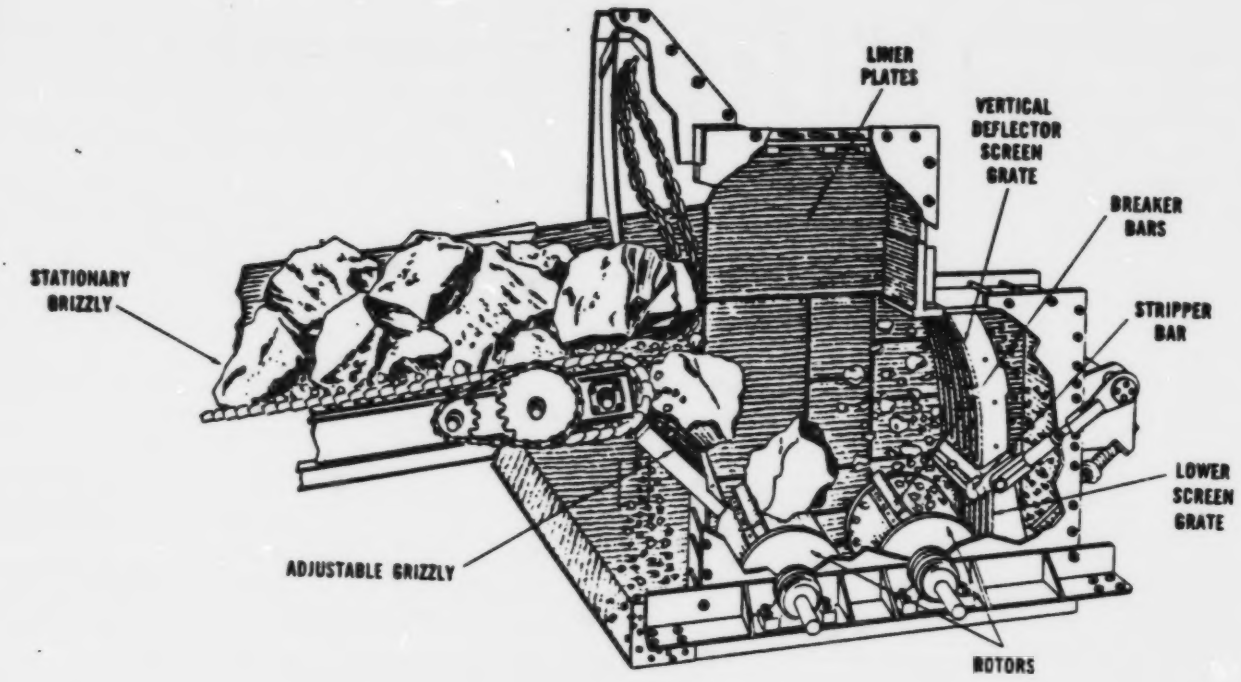

Figure 3: Hardfacing for rotor type impactors (10)

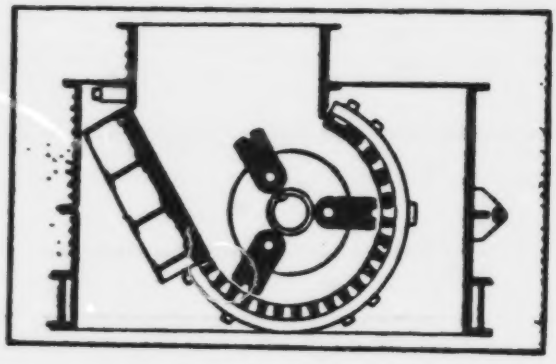

Figure 4: Basic design of a typical hammermill (11)

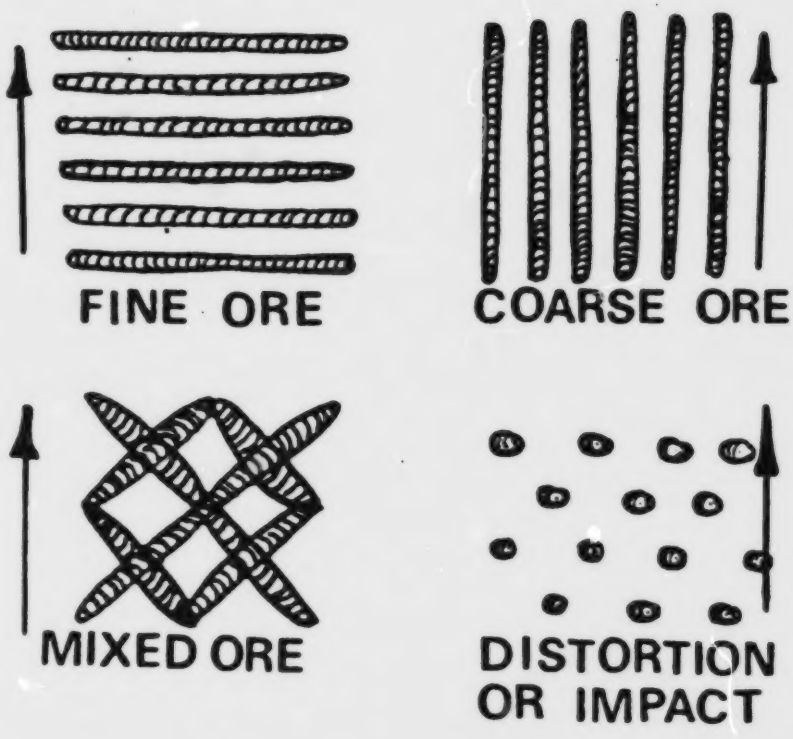

Figure 5: Typical hardfacing patterns used to minimize the rate of wear for different ore conditions

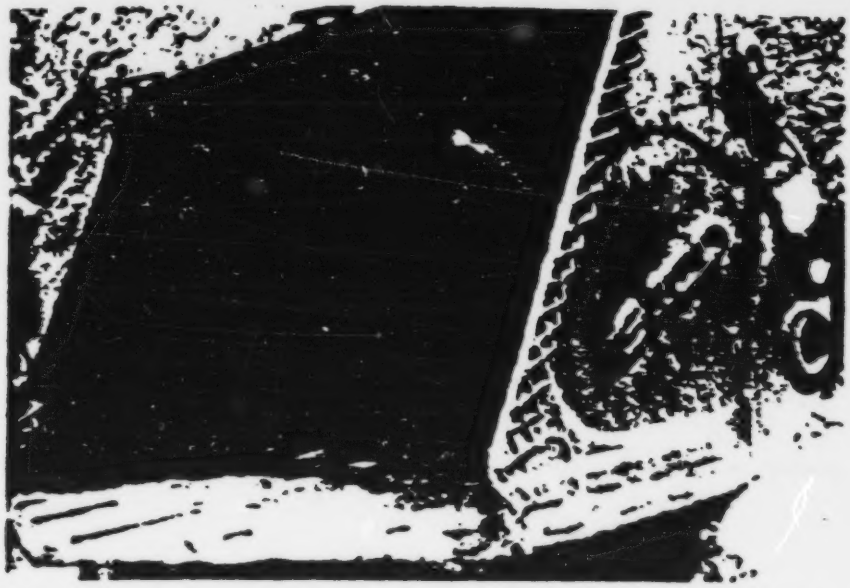

Figure 6: Scoop tram bucket handling ores of mixed size, showing a diamond bead pattern of hardfacing and welded steel inserts.

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APPENDIX A

RESULTS OF INDUSTRIAL SURVEY

Syncrude Canada Ltd.

Peter Blakesley, Chief Materials Engineer

John Whittaker, Senior Welding Engineer

Dave Baron, Junior Metallurgical Engineer

The Syncrude project at Mildred Lake, Alberta, about 40 km north of Fort McMurray, Alberta, produces synthetic crude oil from oil sands in three basic steps; oil sands mining, bitumen extraction, and bitumen upgrading.

Open-pit mining is used to obtain the oil sands utilizing four draglines, four bucketwheels, and approximately 20 km of conveyor belts. The bitumen is extracted from the oil sand by washing with a caustic hot water solution. The final process steps involves fluid cooking and hydro-treating to upgrade the bitumen into synthetic crude oil.

Within the relatively short operating lifetime of the Syncrude project (on-stream date was July 31, 1978), there have been a number of relevant examples of components which required repairs as a result of mechanical failure, wear, corrosion, etc. The justification for equipment repair by either replacement or welding depends on whether the mining operation or the process plant is involved. The mining operation is the bottleneck in the production of synthetic oil, and repairs are usually affected by replacement of broken or worn components. The emphasis is to reduce the downtime. In the oil extraction and upgrading operations, operating equipment problems,

such as cracks and corrosion, can be tolerated during production to some extent and their repair can be planned in advance of scheduled downtimes. The wide variety of process plant equipment would make stocking of replacement parts very expensive, and thus weld repairs are made whenever possible.

The removal of impurity gases in the secondary upgrading process is carried out in hydrotreating units, using hydrogen obtained by reforming natural gas. The reformer tubes arc about 40 ft. long and operate at pressures up to 350 psi and temperatures to 1750°F. A reformer tube assembly is shown in Figure A1. The HK40 reformer tubes are joined to dissimilar metals outside of the furnace sections where the temperatures range between 900°F and 1000°F. The connection of the pigtail expansion loop to the Incoloy 800H weldolet using on Inconel 82 filler wire failed in the HAZ of the 1-1/4 Cr 1/2 Mo material. Temporary repairs were made by welding an 800H tube, 21" long, to the weldolet so that the dissimilar metal weld was moved to an area of lower stress and it also permitted shop welding between the 800H and 1 1/4 Cr 1/2 Mo materials. The repairs have been in service approximately 7 months at the time of writing and so far they have performed satisfactorily.

Recent examination of the reformer tube weld between the carbon steel flange and the HK40 tube, using an Inconel 82/182 combination, has revealed cracks and erosion of the root pass; stress corrosion cracking has been known to cause this type of failure. The tubes have been in service about three years and, apart from experiencing 20 full thermal cycles, they are constantly

subject to operating temperatures at which creep must be considered. The repair of the cracked welds by welding can be accomplished for a total repair bill of $1,000,000 by welding compared to the $8,000,000 price tag associated with retubing the reformer furnace. This involves 456 reformer tube assemblies in a furnace. In both cases, the furnace would be required to be removed from operation, most likely for considerable lengths of time.

The economic factor is not the only consideration. The operating conditions of the tubes in high temperature steam service have possibly contributed to material degradation over the years. If the tubes are repaired and replaced, the properties of the tube in the furnace area could possibly be beyond repair, and this could lead to premature failure when the furnace resumes operation. The lower cost repair versus replacement could lead to a more costly situation in the end.

The slurry from the oil extraction process consists of approximately equal parts of sand and water and could include about 1/2% bitumen. It is pumped to the tailings area in five large diameter pipes. When these pipes exit from the process plant they drop 30 ft. to ground level. The first couple lengths of pipe past the drop are very susceptible to wear; the average life of these pipes (0.3% C) have been about one year. In order to improve this situation, the pipe has been upgraded, wherever necessary, to a NASPIPE N-80 (0.4% C) material. As well as upgrading the pipe material, the sections below the drop at ground level have been coated with an iron-chrome-carbon overlay (4%C, 30%Cr). These sections have been in continuous service for over one year and have yet to be inspected. Based on calculations available in Russian literature, the overlaid pipe should outlast the plain pipe by a factor of about 8.

The same iron-chrome-carbon overlay has been used to build up pump spools and casing. Although the material shows excellent abrasive wear protection, it is not suitable for pump overlays where cavitation (a type of impact wear) occurs. However, slurry pumps surfaced with the same alloy have greatly outperformed other materials. It is possible that changes in the pressure or head to prevent cavitation would then allow surfacing of the pump and thus prevent wear damage.

The other major area which experiences wear problems is the open-pit mining operation. The oil sand is mined by one of four draglines, each bucket is capable of holding 61 cubic metres. The oil sands are extremely abrasive and cause the buckets to wear very quickly. At the present time, the buckets are surfaced with up to 3 tons of Stellite per bucket. The bucket teeth are completely surfaced while the bucket itself is surfaced in various patterns such as spots and parallel beads. The rationale for running in beads with gaps between them is that the oil sands will become caked in these grooves and consequently the sand will wear against itself, thus prolonging the bucket life. Similar surfacing methods are used on the two cubic metre bucketwheel buckets, 14 buckets on each of four machines. The smaller buckets do not experience wear as rapidly as the dragline buckets because the oil sand is in stockpiles. A new approach currently being investigated at Syncrude is to replace bucket teeth with ones made from metal powders. It is expected that sintered metal teeth will be inexpensive to form and will outperform the hardsurfaced teeth presently being used.

urrent problem with the draglines involves the tracks, or tubs, on
cab rotates. Hardened steel rolls running on 4340 steel track
track material to squeeze out on the edges. The only areas
build up are the track edges. The problem with this approach is
consumables and welding procedures which will prevent forming
-affected zones and also maintain the high strength and ductility.

more attractive than replacing the track sections because in order
the track, the cab must be raised, and this is a very difficult
. The decision on improving the track has yet to be made, but it
ive redesign of the roller and track assembly.

spection of the masts on the draglines revealed the presence of
the tubular connections and were associated with welding. These
repaired as required.

topic relating to repair by welding dealt with the general topic of
rature pressure vessels. Steel vessels clad with stainless steel and
entirely of chrome-moly steels were of interest. Control of welding
to avoid sensitization of the stainless steel in the clad vessels is
importance, as well as preventing temper embrittlement of the Cr-Mo
pair procedures without preheat, such as temper bead and half-bead
, are areas of interest to Syncrude.

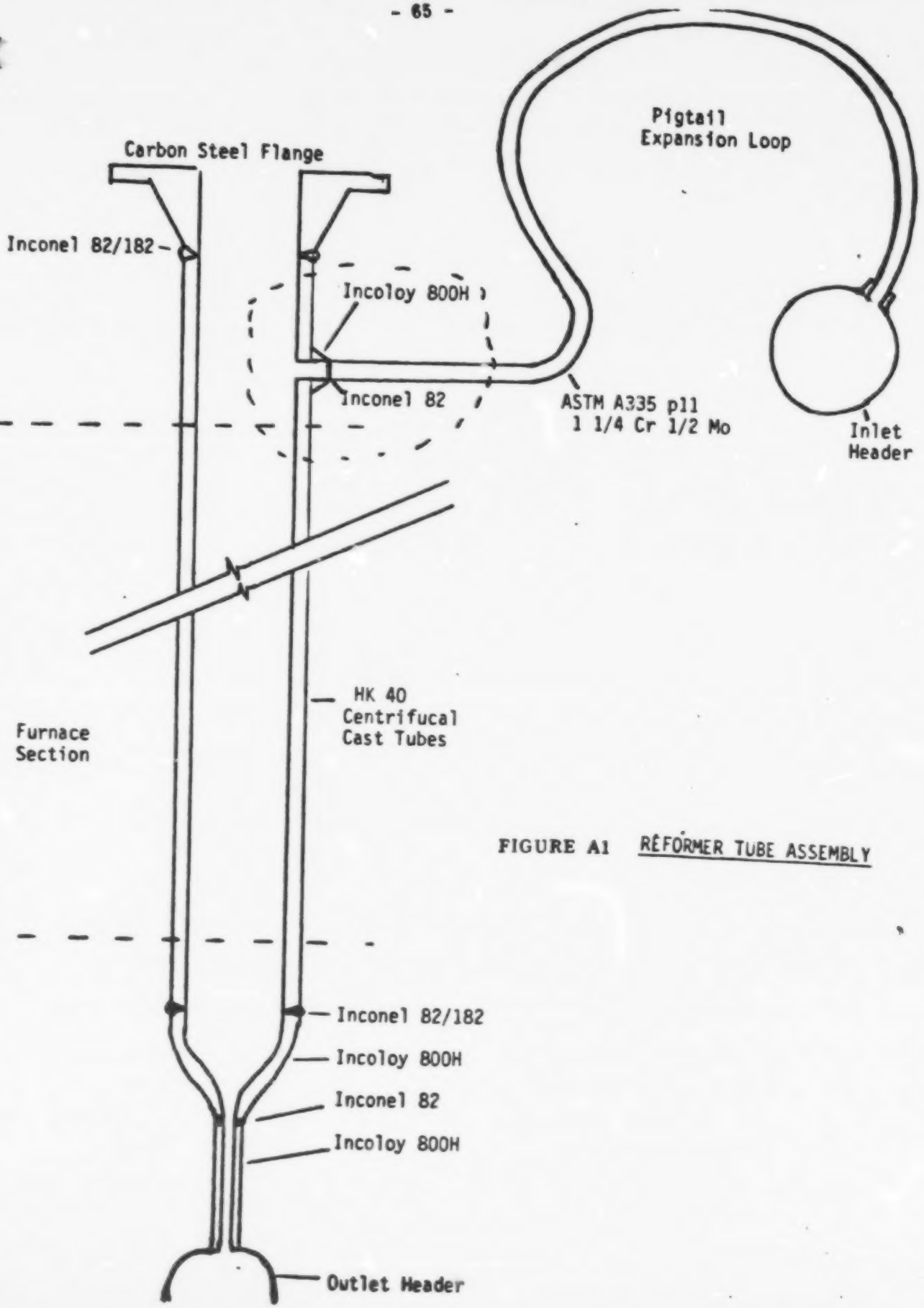


FIGURE A1 REFORMER TUBE ASSEMBLY

Ontario Hydro

Mark Tinkler, Group Leader, Welding Research

Scott Lawson, Head, Welding Section

The welding group at Ontario Hydro Research are currently involved in a number of projects relating to repair by welding. Successful repairs have been made to various components such as pressure vessels, iron castings, and turbine runners.

Many repair situations involve cracks in ferritic steels which were stress relieved when they were originally fabricated. Therefore, following repair welding, stress relief of the repaired area is required. When heat treatments are done in situ, one must consider numerous aspects such as differential thermal expansion, overheating of adjacent components, and creep. The use of a stress relief treatment is sometimes not possible due to inaccessibility and/or concern over the heating effects. Apart from the possibly detrimental effects of post weld stress-relief, listed above there are good reasons for using it such as:

1. reducing the residual stresses due to the non-uniform heat distribution during welding;
2. reducing the hardness of the heat-affected zone; and
3. reducing the hydrogen concentration in the vicinity of the weld repair.

These factors can minimize the likelihood of hydrogen-induced delayed cracking during repair.

An area of current interest and recent experience within Ontario Hydro involves using a temper bead welding technique for repairs to nuclear plant equipment. The beneficial effects of PWHT are available without the problems associated with heating. Temper bead welding is allowed in the ASME Boiler and Pressure Vessel Code, provided that the welding procedure is qualified under identical repair conditions. Hydro has used this method primarily with A516Gr70 steel, but some repairs have been qualified for A515 Gr70 material also.

A general area which would be of interest to Hydro is the development of procedures for in situ repair to a wide range of materials and components. Consideration should be given to the condition of the component before repair commences, the residual stress distribution following repairs (particularly using the temper bead technique), and whether the maximum hardness is critical as in sour gas or H_2S service. All repair procedures should be conducted in such a manner that PWHT would be unnecessary. The service environment of stainless steel components is very important when repairs are considered.

One of the most active areas in weld repair at Ontario Hydro involves rebuilding turbine runners and casings which have been damaged by cavitation. This is done by building up areas with mild steel electrodes to just below the finished dimensions and then surfacing with a cavitation-resistant alloy, usually austenitic stainless steel. Repairs are done using a SMAW process in most instances. The major concern with these

repairs is related to distortion because of the unbalanced welding which could lead to vibration problems when the turbine is put back in operation. This type of repair is quite successful, but the parent material adjacent to the repair seems to become even more susceptible to cavitation damage.

The welding section has recently been receiving frequent inquiries related to the use of hardfacing. Apart from originating the proposal for a study of hardfacing for the coal handling plants, the personnel at Hydro have had little experience with surfacing methods. The project is currently in progress and should provide information relating to abrasive wear. This is only one small area which hardfacing materials have been proven to be effective. There are numerous potential applications for surfacing technology within Hydro which have yet to be identified.

The Steel Company of Canada Limited

Neil A. Paolini, Specialized Engineering

The experience with weld repair and reclamation at Stelco has been primarily in the weld repair side. The examples cited were mainly crack repairs with some build-up and some hardsurfacing. The main process equipment requires fewer repairs than auxiliary plant and structures.

The top section on the outside of a blast furnace is made of a series of skirts which are riveted together. Cracks were noticed running across rivet holes and some cracks were several feet long. The repair procedure was as follows:

1. the ends of the cracks were drilled out and checked with dye penetrant to ensure that the crack tip was removed;
2. preheated bars (approx. 1" x 6" x 1/2" thick) were welded across the cracks, with a spacing of about 3 to 4 in.

When the preheated bars cool, they put the crack in compression, and thus prevent the crack from extending.

The by-products of the coke ovens are highly corrosive gases which are condensed in stainless steel pressure vessels (15 psig). The condensers do not last very long and consideration is being given to make new condensers from either titanium or other types of stainless steel. Titanium is difficult to weld because it absorbs hydrogen very easily and becomes embrittled. The increased problems associated with welding Ti were not considered to be justifiable and stainless steel will continue to be used for the condensers.

A crucial area of steel production involves the forming and rolling of the steel ingots in the US Slab Mill, breakdowns in this area could halt the complete operation. The main problem area in the mill concerns the crane rails which are used to transport the billets. The design originally allowed for 40 ton lifting capacity, but over the years the crane has been redesigned to be able to lift 60 tons, 80 tons, and now 100 tons. The crane runway has been made stronger but the rails have not changed because of space limitations in the building, and therein lies the problem. The crane rails are particularly prone to fatigue damage and wear. The sides of the rail also get squeezed out due to the self-centring action of the crane wheels.

When cracks are noticed in the rails they are repaired temporarily by placing a splice across the failure until a complete repair can be made. The splicing opertion requires about 1 1/2 hours to complete. The consumables and welding procedures used for rail repairs are chosen to develop a minimum amount of martensite in the heat-affected zone. Adequate preheat using an E7018 electrode is used for build-up of the crane rail, followed by hard surfacing the top half of the rail with a suitable electrode. This method of repair requires a duplication of effort, a temporary repair followed by a permanent repair. This has been recognized and studies are currently underway to affect repairs without duplication of effort. These involve placing a splicing bar on the rail and then building up the rail ball by welding.

There are numerous cases cited in the literature where rolls in the steel mills are resurfaced when the faces have worn excessively. Although Dofasco is reported as having an ongoing project to rebuild worn steel rolls, Stelco does not do so. Instead, they use the new rolls on the thinnest sheet and periodically move them towards the thickest plate, or initial ingot reduction, until they are no longer usable, and then they are scrapped. Optimum control of roll speed along the line and exact sequencing of operations has been useful in extending the period between roll changes.

The plate width is maintained using edger rolls. The bottom part of the housing holds the actual roll assembly and is subjected to severe impact loading. As a result, the housing has gradually worn down over the years (three edger rolls have seen 8, 10, and 12 years service) and shims have been added as required to eliminate the slack. However, the housing has become so thin that there is concern over the use of any more machining, and the repair or replacement of the part is being considered. A new set of edge-roll housings would cost $800,000 and require two years for delivery. The refurbishing of the existing housing could be done by either casting a new housing, fabricating a new housing, or by building up the worn surfaces. The latter method is preferred in terms of being the most straightforward and could invariably be completed more quickly and at less cost than waiting for a new housing.

Galvanized steel sheet is a common product of steel mills. The galvanizing is done by running hot steel strip through molten zinc in pots whose dimensions are 8 ft x 8 ft x 6ft deep. The life of these zinc pots varies from 2 months to about 12 months. The zinc pots are made from a proprietary Stelco material called Spelterpan (0.4C, virtually no Si). The low Si content makes the material very difficult to weld since there are no deoxidants. The major problem with the zinc pots relates to the operating of the galvanizing process. The optimum bath temperature is 880°F but frequently the wall temperature is higher. Above 900°F an iron-zinc compound readily forms up to 1/2 in. thick, becomes brittle, and spalls off. The corrosion rate doubles for every 10°F above 880°F, and the welds are particularly sensitive to damage. By observation, it was noticed that the Si at the stub end of the electrode was higher than the start, an thus the electrodes were cut in half to weld the Spelterpan to keep the Si below values that are detrimental. The highly localized temperatures at the pot walls are due to the heating method. Resistance strip heaters and gas torches are used to heat the zinc, both of which can increase local temperatures, and thus increase corrosion. The use of stainless steel or stainless clad materials is not attractive because the welds are prone to accelerated corrosion attack and they also have poor conductivity which leads to local hot spots.

Rolled steel plates are cut to size using shears made of 4140 steel which are hardfaced along the cutting edge with tool steels using either MIG or TIG processes. The shear blades are part of their continual maintenance program and hardsurfacing is even done on new blades. This is one of the many applications of hardfacing or surfacing at Stelco, generally it is not considered as a repair procedure.

A final area of concern expressed by Stelco involved the use of stress relief heat treatment. It was felt that stress relief after welding was used excessively and could be omitted without detrimental effects. This could be applied to both primary fabrication and weld repairs.

APPENDIX B

PROPOSAL FOR A STUDY ON PROPERTIES OF REPAIR WELDS

PROPOSAL FOR A STUDY ON PROPERTIES OF REPAIR WELDS

1.0 Introdurtion

The main text of this report has identified a need to investigate the properties of repair welds in several critical areas. The materials used in the critical areas are generally thick section, alloy plates and other romplex structures. When repair welding has been completed, stress relief is usually specified as a safeguard measure.

In a study on the fracture mechanics of repair welds in ferritic stainless steel castings, Purazrang (26) measured the fracture toughness of the casting, weld metal, and the heat-affected zone (HAZ) both before and after stress relief. In the as-welded condition, his results showed major differences in the values of the allowable defect sizes in the three regions. The HAZ and weld metal toughness was improved by stress relieving, but the allowable defect size in the weld metal was still below that of the casting. His work showed that the fracture toughness of the weld metal, rather than the casting, is the critical parameter to consider following repair welding. He also recommends a stress relief treatment after welding.

In a summary article on weld repairs of power-plant components, Lawson and Mills (25) note that heat treatment after repair welding is limited due to the probability of unacceptable creep deformation. The possibility of creep damage is particularly likely in components which carry large dead loads. Another limitation to repairing is the restraint against thermal expansion by rigidly connected parts. When a structure is prevented from free thermal expansion during heating, residual stresses develop when the heated parts cool to ambient temperatures. Residual stresses can also develop when local thermal treatments are employed. The superposition of local and long range stresses combine directly and affect the integrity of the repair. In order to avoid these problems associated with stress-relief, welding techniques have been developed to sufficiently refine the HAZ structure so that the welds could be used in the as-welded condition (24). The welding procedure involves electrode manipulation to prevent HAZ hardening and thus eliminates the need for stress relief. This procedure is known as temper bead welding and can also be used for primary fabrication.

A repair procedure known as half-bead welding, which is comparable to temper bead welding, is approved by ASME for repair welding without stress relief. Half-bead repairs involve grinding out half of the root bead and then complete the welding as per normal practice. This is a troublesome procedure and is not as reliable as temper bead welding.

In order for temper bead methods, and variations which will likely develop, to be accepted and widely adopted, information relating to the fracture toughness properties after welding is required. If it can be shown that the material possesses adequate toughness to prevent failure without stress relief, and that there is good reproducibility of results, then temper bead welding will be better utilized. Not all steel grades would be used for applications which would be suitable for repair welding without subsequent heat treatment. Therefore, only a few selected grades would need to be included in a study to demonstrate the toughness attainable with temper bead welding.

Heavy section steels used for pressure vessels in Canada are usually one of the following ASTM grades: A515 Gr70, A516 Gr70 or A533 Grade B Class 1. These alloys fall under the classification of carbon-manganese steels. In the near future, Cr-Mo steels will become increasingly more important in high temperature, hydrogen rich environments as would be expected in coal liquefaction plants, for example.

A study of repair welding techniques, and their resultant properties, using the four steels mentioned in the previous paragraph would consequently provide useful information for most national industries. The variables studied would include sufficient data for analysis to determine critical defect sizes, and thus the subsequent acceptance of the repair procedure.

2.0 Experimental Program

The temper bead method of repair welding would be examined for the four steels mentioned previously (A515 Gr 70, A516 Gr 70, A533 Grade B Class 1, and A387 Grade 22 Class 2). The program will primarily address the measurement of fracture toughness to determine whether repair welding without subsequent heat treatment is viable. The crack tip opening displacement (CTOD) procedure outlined in BS 5762, 1979 will be used in conjunction with PD6493, 1980 to establish the maximum allowable defect size in the following regions: the unaffected base plate, the weld metal, and the heat affected zone. Quite often, sections which are repair welded are circular in nature. This means that the toughness properties in the directions parallel, transverse, and perpendicular to the rolling direction must be examined to determine the worst possible case. For comparison purposes, CTOD tests will be conducted on temper bead repairs for both as-welded and stress-relieved samples of simulated repair welds.

Apart from toughness requirements, repair welds returned to sour gas (H_2S) service have a hardness limitation of 250 VHN to prevent hydrogen cracking. In temper bead welding the maximum hardness can be controlled through specification of preheat/interpass temperatures. In non-corrosive environments, temper bead repair must be conducted in such a manner as to prevent hardnesses from exceeding 300 VHN. To meet these requirements, several preheat/interpass temperatures will be used for repair welds and the dependence between the hardness and temperature will be determined for each alloy.

The microstructures of the repairs will also be examined for a number of reasons. The refinement of the HAZ and the structures observed not only provide an indication on the practical aspects of the repair procedure, but they also give an indication of the fracture toughness properties.

A summary of the experimental program outlined above, and estimates on the manpower and financial requirements are given in Table 1.

The project will be approached from both a laboratory environment and actual field trials. The difficulty of accurately locating the notch in the HAZ for CTOD tests can be overcome by using Gleeble specimens. These samples are produced by carefully controlling thermal cycles to represent various welding conditions. Gleeble samples can be used to study the response of each steel to simulated

welding cycles and can investigate the properties in all of the rolling directions. The microstructures and hardness variations with different preheat/interpass temperatures can also be determined with Gleeble samples. Multiple thermal treatments to simulate multipass repair welding can easily be accommodated using Gleeble tests. Although the Gleeble experiments can be used to measure a range of conditions, they do not adequately reproduce the complex thermal and restraint conditions of repair welds. Therefore, typical temper bead repairs will be examined for all of the steels. These welds will be metallographically examined and hardnesses measured to ascertain the effects of the temper bead technique. The repair welds will also be sectioned to produce CTOD specimens to be tested at the transition temperature; a complete transition curve would not be required.

The program outlined above would require two years from the starting date to complete. The first year would focus primarily on Gleeble simulations and related testing. The following year would be allotted to preparation, examination, and testing of temper bead repairs, and for compilation of a final report.

The theme throughout the study would be to establish information crucial to the necessary evaluation of tolerant flaws in steels commonly used in Canada. Measurement of the properties before and after stress relief will also provide data which would allow proper repair procedures to be developed.

Experimental Program for the Study of Properties of Repair Welds

1.	Materials A515Gr70, A516Gr70, A533Grade B Class 1, and A387 Gr22 Class 2 Electrodes	 $3000 $ 500
2.	Preparation for Welding Machining of repair examples Literature review of applicable temper bead procedures Gleeble sample preparation	 $8000 $2000 $6000
3.	Welding - includes verification of TB Method - repairs made for CTOD testing - repairs to investigate preheat/interpass vs hardness.	$6000
4.	Gleeble Simulations Mechanical Testing (including machining) 36 transitions curves 16 preheat/interpass vs. hardness	$12000 $129600 $8000
5.	Metallography	$10000
6.	Report and Professional Time	$20000
		$ 205100

APPENDIX C

Special Seminar Programs

Held at the

Welding Institute of Canada

TORONTO CHAPTER
SEMINAR AGENDA
March 17, 1982

A One-Day Seminar Presenting a Program Emphasizing the Latest Technologies of the Submerged Arc Welding Process

9:00 a.m. – 5:00 p.m.

Chairman: R. A. Dunn, Special Consultant to the Welding Institute of Canada and the Canadian Welding Bureau

"ONE-SIDED SUBMERGED ARC WELDING"
– Mr. N. R. Ellenor, National Sales Manager,
Lincoln Electric Company of Canada Ltd.

"FIELD APPLICATIONS OF SUBMERGED ARC WELDING"
– Mr. J. Orr, Construction Welding Supervisor,
Dominion Bridge – Ontario

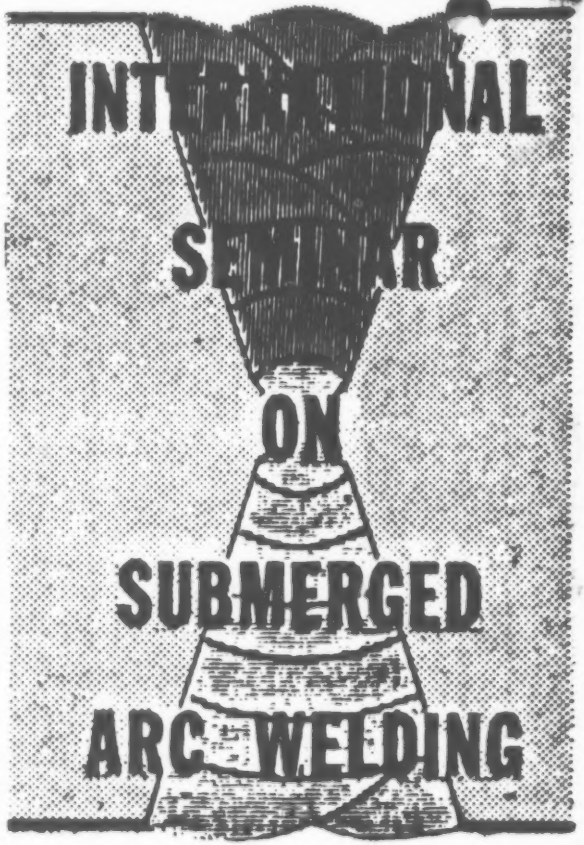
"SUBMERGED ARC WELDING OF ARCTIC GRADE LINE PIPE STEEL"
– Dr. John Garland, Director,
Oerlikon – United Kingdom

Lunch.

"INCREASING PRODUCTIVITY THROUGH THE USE OF MULTIPLE WIRE PROCESSES"
– Mr. G. D. Uttrachi, Manager of Market Development – Welding Department,
Union Carbide Corporation, U.S.A.

"DESIGNING WELDING FIXTURES AND MATERIAL HANDLING EQUIPMENT TO MAKE SUBMERGED ARC WELDING MORE PROFITABLE"
– Mr. L. Neal Bannister, Vice-President,
OGDEN Engineering Corporation, U.S.A.

"SQUARE WAVE A.C. POWER SOURCES"
– Mr. F. J. Grist, Vice - President Research,
Miller Electric Manufacturing Company, U.S.A.



MARCH 17, 1982

PRESENTED BY

THE TORONTO CHAPTER

WELDING INSTITUTE OF CANADA

INSTITUT DE SOUDAGE DU CANADA

HI-TECH APPLICATIONS IN WELDING PROCESSES

March 22 and 23, 1982

A Special Seminar organized by the Welding Institute of Canada / Institute de Soudage du Canada with assistance from the Ontario government "Training in Business and Industry" (TIBI) Program, and in association with Sheridan College of Applied Arts and Technology.

Seminar Agenda

DAY 1

9:00 am	Introduction	Lawrence D. Parkinson, Technical Information Resource Centre WIC/ISC Oakville, Ontario
9:30 am	Analysis of Requirements for Automated Systems	Dr. W. H. S. Lawson, Supervising Engineer Ontario Hydro Research Toronto, Ontario
10:15 am	Coffee Break	
10:30 am	Automation for Welding "Present State"	Jim Downey, President Mark VI Industries Buffalo, New York
11:15 am	Solid State Power Sources and Controls for Welding	Mike Eckert, Technical Representative Hobart Brothers of Canada Ltd. Woodstock, Ontario
12:15 pm	Lunch	
1:00 pm	Advanced Weld Mechanization	Brian Lang, Manager of Operations C. R. C. Calgary, Alberta
2:00 pm	New Directions in Plasma Arc	Dan O'Hara, Director of Engineering & Development Thermal Dynamics Corporation West Lebanon, New Hampshire
3:00 pm	Break	
3:15 pm	Micro Process Control for GTAW	Doug Power, President Power Weld Engineering Mississauga, Ontario

DAY 2

9:00 am	Developments in Arc Control Through Solid State Devices	Ron Jackson, President Cyclomatic Inc. San Diego, California
10:30 am	Coffee Break	
10:45 am	Micro Process Control	Jean-Paul Boillot, Director Quebec Centre WIC/ISC Varennes, Quebec
12:00 pm	Lunch	
1:00 pm	Image Joint Tracking	Jean-Paul Boillot, Director Quebec Centre WIC/ISC Varennes, Quebec
2:15 pm	Arc Welding Computer Simulation	Brian Graville, Manager Research & Development WIC/ISC Oakville, Ontario
2:45 pm	Coffee Break	
3:00 pm	Developments in Arc Welding Robot Systems	Ken Adams, Robot Specialist ASEA Ltd. Mississauga, Ontario